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THE DISTRIBUTION OF EXTRAGALACTIC NEBULAE *

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Abstract. Counts of extragalactic nebulae have been made on plates taken with the 20-inch Carnegie astrograph of the Lick Observatory. The area of the sky for which the results are published in the present paper extends in right ascension from 12^h to 18^h and in declination from -20° to $+20^\circ$. The limiting magnitude of about 18.4 has been made as nearly as possible constant over this entire region through the use of uniform procedures and the application of corrections for systematic errors. The principal data are given in a table containing the counted numbers of nebulae in each square degree together with corrections to reduce these numbers to a uniform basis, and the results are portrayed by means of a chart giving contours of equal numbers of nebulae per square degree.

In addition to a very irregular boundary of the zone of avoidance, several more or less detached areas of galactic obscuration are apparent on the chart. In higher latitudes, where the effect of galactic obscuration should be small, the distribution of nebulae is still so far from random as to suggest strongly that clustering is a very general feature of the distribution.

The distribution of surface density of nebulae in Coma-type clusters has been studied in a very preliminary way and is found to be well represented by de Vaucouleurs' empirical formula for the distribution of light in elliptical nebulae. The association of clusters to form larger aggregations or clouds of nebulae seems to be a rather general feature of the distribution.

I. INTRODUCTION

The problem of nebular distribution may be considered from two aspects. One is concerned with the way in which the nebulae are distributed over the surface of the sky, and the other with their distribution in depth. Extensive nebular counts, or surveys, provide the observational material for both investigations but the approach is very different.

A survey in depth requires that nebulae be counted in properly selected sample areas to specific limiting magnitudes that cover as wide a range as possible. Nearly twenty years ago Hubble carried out the principal survey in depth that has been made to date.¹ More recently he has outlined the direction that should be taken in an improved and definitive survey.² The requirements are very severe, for the limiting magnitudes must be determined on a highly accurate scale. In order to correct for the larger red shifts, the intensity distribution in the spectra of the nebulae must be known to much shorter wave lengths than those covered by the adopted magnitude system. Since it is not possible to determine the intensity distribution in the far ultraviolet, it is desirable to make the survey in the region of longer wave lengths. Even if proper allowance can be made for the spectral energy distribution, the corrections for the red shift depend on whether or not the shift is due to recessional velocity. It is not at present clear what allowance should be made for the excess reddening of very distant nebulae as observed by Stebbins and Whitford.³ Observers at the Mount Wilson Palomar Observatories are laying the foundation for what it is hoped will be a definitive survey in depth.⁴ When this survey is complete, it will provide essential information not only on a pos-

sible large-scale radial density gradient of the universe, but also on the nature of the red shift and on the curvature of space.

A study of the surface distribution of the extragalactic nebulae requires quite a different observational approach. For this purpose the plates should cover a very substantial connected area of the sky, but the counts may be restricted to a single limiting magnitude. This limiting magnitude need not be determined with high precision but it should be constant over the region surveyed. Smaller-scale inhomogeneities can be observed than those revealed by a survey in depth.

Suitable material for a nebular survey over the surface of the sky is provided by a series of 1246 plates taken with the 20-inch Carnegie Astrograph at the Lick Observatory. These plates are the first of two series in a proper motion program originally planned by Wright.⁵ It is intended that the second series shall be taken after an interval of some decades. The plates cover the entire sky north of declination -23° , with uniform exposures of two hours centered on the meridian. Perhaps their greatest advantage lies in the fact that each plate covers an area 6° square with the plate centers not more than 5° apart in each coordinate. Thus each plate has a generous overlap with at least three and usually with four of its neighbors. Nebulae in the overlaps are most useful in reducing the counts to a common standard.

The number of nebulae photographed to a limiting magnitude of 18.3 or 18.4 is of the order of a million. Nebular counts were started by the authors late in 1947, and in the interest of uni-

* *Astronomical Journal*, 59, 285, 1954. A preliminary report of this work was published in *Proc. Amer. Phil. Soc.* 94, 13, 1950.

formity, all the plates are now being counted by them. Five of the earlier plates were counted by Mayall. The counts are about 44 per cent complete and are being continued as rapidly as possible.

For purposes of discussion the sky has been divided into nine areas. Areas I to IV inclusive cover 6^h intervals starting at 0^h and lying between -23° and $+20^\circ$. Areas V to VIII cover the same intervals in right ascension from declination $+20^\circ$ to $+60^\circ$. Area IX comprises all of the polar region north of $+60^\circ$. Only the counts in Area III, $\alpha = 12^h$ to 18^h , $\delta = -23^\circ$ to $+20^\circ$, have been completely reduced to date. The results of this discussion form the subject of the present paper.

II. THE PHOTOGRAPHS

The photographic plates are seventeen inches square and cover a field of slightly more than 36 square degrees. They were coated by the Eastman Kodak Research Laboratory with emulsion of type 103a-O. The five emulsions used in Area III were uniform in average sensitivity to a very satisfactory degree, with an extreme range of less than 0.2 mag. in average limiting magnitude, as determined from the nebular counts. Care was taken to maintain uniformity in development and to guard against deterioration of the plates in storage.

The plate centers for the entire program are referred to the equator and equinox of 1950. From $\delta = -20^\circ$ to $\delta = +35^\circ$, the centers are spaced 20^m apart, starting at $\alpha = 0^h$. From $\delta = +40^\circ$ to $\delta = +50^\circ$, the increments are 24^m. North of $\delta = +50^\circ$ the increments are as follows: for $\delta = +55^\circ$, 32^m; $\delta = +60^\circ$, 36^m; $\delta = +65^\circ$, 40^m; $\delta = +70^\circ$, 48^m; $\delta = +75^\circ$, 60^m; $\delta = +80^\circ$, 90^m; $\delta = +85^\circ$, 144^m. All plates are centered accurately with the errors seldom exceeding 1' in either coordinate. While the usable field on each plate is 6° square, the plate centers are no more than 5° apart, so that except for the southern band of plates, one degree around the edge of each plate is duplicated on adjacent photographs.

Each exposure was started 1^h1^m before the center of the field crossed the meridian. At the end of an hour the exposure was interrupted for 2 minutes. During this interval a one-minute exposure centered on the meridian was taken with the telescope shifted approximately 1' in right ascension. The telescope was then returned to its original position for the second hour exposure.

A coarse wire grating of $\frac{1}{4}$ -inch spacing placed in front of the lens was used throughout. This grating gives first-order images 4 magnitudes fainter than the primary images and separated from them by 0'.24. It reduces the limiting magnitude by 0.3 mag. Both the grating images and the short exposures are a slight hindrance in the nebular work, but they are important in an astrometric study of the material when the positions of bright and faint stars are compared.

Occasionally exposures were interrupted by clouds. Some plates of deficient effective exposures were used in the survey if the deficiency did not exceed 20^m. In such cases suitable corrections were applied to the counts.

III. THE COUNTS

The uncorrected nebular counts per square degree for Area III are given in Table I. The numbers are arranged so that north is at the top, east to the left. Plates in each 5° zone of declination are tabulated as separate groups. Above each block of counts representing the 36 square degrees on a plate are certain designations pertaining to that plate. The plate number is given at the upper left. Below this is the initial of the observer who counted the plate, followed by a small letter indicating the emulsion. The right ascension of the plate is given at the upper right and below it is the complete plate factor, F, defined below. Several plate numbers are followed by asterisks, which refer to the notes following the table. The notes list the plates deficient in effective exposure time and those omitted from the solution for the various correction factors because of outstanding discrepancies with their overlapping neighbors.

Although the numbers of nebulae per square degree are tabulated, the original counts were actually recorded in 10' squares. The counting procedure is in general uniform throughout. The plate is mounted in a frame with a motion in the north-south or y direction. The observing microscope moves in the east-west or x coordinate. Scales reading to 1' permit the fairly accurate location of the area to be counted. In the focal plane of the microscope there is a square 10' on a side defined by cross hairs. This is first centered on the northwest 10' square of the plate, and the number of nebulae in that square is counted and recorded. Counts are made across the plate by 10' intervals from west to east. Then the plate is moved south by successive 10' intervals and the process is repeated in the same

TABLE I. AREA III, UNCORRECTED COUNTS OF NEBULAE PER SQUARE DEGREE

$\delta = -20^\circ$		788 12 ^h 00 ^m S b 1.022 35 36 38 27 22 36 68 69 37 49 73 40 51 44 34 49 51 36 31 39 54 67 41 62 21 34 36 53 30 15 29 13 23 28 14 10	1512 12 ^h 20 ^m S h 0.953 56 73 61 41 30 33 41 46 35 37 59 51 31 77 36 24 33 49 42 39 19 25 24 27 31 50 52 47 31 18 39 31 32 29 29 14	469 12 ^h 40 ^m S a 0.822 56 49 50 51 32 50 77 53 43 45 42 60 61 61 54 57 48 66 77 65 50 50 42 59 82 81 72 45 46 57 59 69 54 45 49 51	476* 13 ^h 00 ^m S a 0.999 50 53 62 70 146 40 54 72 49 61 70 56 57 63 84 44 40 51 57 72 50 33 51 47 60 74 49 53 40 58 37 57 47 48 60 54	
		803 13 ^h 20 ^m S b 0.892 50 54 35 74 50 38 33 44 30 39 41 63 48 28 58 20 48 60 39 83 41 33 47 39 43 55 33 56 40 53 45 29 49 45 49 37	1164 13 ^h 40 ^m W e 0.834 34 27 33 30 30 59 30 33 57 48 25 24 63 49 69 67 52 38 35 31 38 33 50 48 22 25 24 25 37 51 35 42 40 31 41 44	1574** 14 ^h 00 ^m S h 1.780 17 28 19 14 14 12 20 19 22 22 20 13 25 28 24 29 24 20 18 20 11 30 25 16 16 19 23 27 18 7 16 20 23 28 19 11	789** 14 ^h 20 ^m W b 0.415 30 31 48 32 35 33 43 40 51 32 44 44 52 59 50 62 39 46 32 59 47 37 24 33 25 32 25 25 29 37 36 47 29 32 46 33	1590 14 ^h 40 ^m S h 0.978 10 24 21 35 12 5 19 23 36 18 15 27 21 32 21 15 16 21 26 31 20 27 11 15 23 33 38 15 21 16 17 17 19 20 13 7
		470 15 ^h 00 ^m W a 0.825 25 15 5 12 16 21 19 14 13 22 18 21 35 26 16 33 24 29 35 25 20 22 10 31 39 23 22 28 25 31 23 20 19 20 32 40	852* 15 ^h 20 ^m W b 0.885 34 23 24 28 20 25 19 9 9 16 11 15 22 12 10 15 16 8 20 24 17 16 17 21 18 29 17 14 15 21 35 31 30 16 27 27	1254** 15 ^h 40 ^m W f 1.522 8 5 17 7 11 13 5 5 13 10 6 14 10 3 9 12 6 10 6 4 5 1 10 5 4 5 9 9 14 22 19 12 13 15 32 37	1604 16 ^h 00 ^m S h 1.047 0 1 4 5 3 10 4 1 6 4 2 4 2 5 6 5 5 5 7 3 8 11 3 4 3 0 7 7 8 4 4 2 9 7 5 2	1208 16 ^h 20 ^m S e 0.879 2 1 2 0 2 2 2 4 2 3 1 3 0 1 0 1 1 3 1 0 0 0 2 1 1 1 1 1 1 5 0 0 0 2 10 0
		874 16 ^h 40 ^m S b 1.000 0 2 0 1 1 2 0 0 1 1 2 0 3 1 0 1 6 1 5 3 5 2 1 1 0 1 0 0 1 2 2 1 0 0 0 0	888 17 ^h 00 ^m S b 0.879 0 0 0 1 2 0 1 1 3 6 3 1 0 1 3 3 0 0 1 1 5 2 3 7 0 0 0 2 2 0 0 0 0 1 2 0	529 17 ^h 20 ^m S a 0.914 0 0 0 0 0 0 1 0 0 1 2 1 0 0 0 0 5 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0	526 17 ^h 40 ^m S a 0.914 0 0 0 0 0 0 0 1 0 0 2 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0	487 18 ^h 00 ^m S a 0.914 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 1 0 0 0 0
$\delta = -15^\circ$		1532 12 ^h 00 ^m S h 0.975 45 39 49 42 54 52 63 66 54 44 45 39 49 45 41 37 77 57 49 39 29 23 49 76 51 52 29 38 48 65 47 36 50 39 28 32	1568** 12 ^h 20 ^m S h 1.695 21 24 29 57 27 19 32 44 39 79 44 30 35 26 40 35 27 28 35 24 46 26 23 17 25 30 31 19 14 15 24 37 30 16 15 6	812 12 ^h 40 ^m W b 1.155 72 44 35 37 15 22 41 32 24 27 15 45 139 80 34 27 54 34 165 50 42 49 22 31 48 40 36 45 19 17 47 34 51 46 27 43	774 13 ^h 00 ^m S b 0.844 68 34 51 78 119 76 58 55 91 111 152 58 56 82 66 92 111 169 72 82 85 128 121 193 67 86 143 115 134 51 63 54 64 102 154 33	
		814 13 ^h 20 ^m S b 0.977 73 66 82 68 56 68 87 62 46 43 55 55 90 40 41 59 54 45 50 53 37 56 63 40 29 47 55 113 48 31 26 29 32 57 55 28	462 13 ^h 40 ^m S a 1.077 56 37 46 59 52 50 52 66 56 42 48 71 63 49 41 47 36 59 49 34 46 34 38 23 25 26 34 37 33 19 27 27 34 23 22 24	1223 14 ^h 00 ^m W f 0.716 49 57 33 54 97 89 53 49 52 29 53 62 38 32 39 36 48 63 35 50 31 25 77 41 28 37 25 32 28 34 26 39 17 31 30 27	1587 14 ^h 20 ^m S h 1.329 28 9 13 13 12 18 14 18 14 13 23 25 17 21 36 20 14 19 14 16 31 30 24 20 17 20 50 44 13 8 6 13 27 13 12 9	1601 14 ^h 40 ^m S h 1.202 14 16 21 23 12 18 18 32 25 18 22 12 31 17 19 17 13 16 30 22 16 19 18 10 16 16 24 37 16 15 13 21 21 18 4 2
		475 15 ^h 00 ^m S a 0.788 19 12 22 28 18 22 48 31 31 36 23 51 26 21 22 18 33 27 17 14 9 18 25 39 10 12 7 27 32 8 17 7 12 16 15 15	841 15 ^h 20 ^m S b 1.238 16 20 14 16 11 8 12 18 19 19 12 18 26 18 12 11 21 14 14 11 16 8 11 9 12 14 9 7 15 7 20 12 17 17 12 10	504 15 ^h 40 ^m M a 1.029 9 13 32 18 6 14 13 19 29 21 9 15 18 25 19 32 27 21 45 36 45 25 22 11 26 24 48 49 64 11 13 25 46 26 17 7	483 16 ^h 00 ^m S a 1.401 7 15 13 12 21 12 13 12 18 17 16 10 13 14 19 16 14 17 15 5 9 15 26 19 14 5 10 9 11 10 11 3 10 7 12 18	871 16 ^h 20 ^m S b 1.000 5 3 3 6 4 5 7 5 4 5 1 7 4 1 0 0 3 4 8 4 3 5 7 3 4 3 1 6 6 5 5 5 5 3 3 2
		850 16 ^h 40 ^m S b 1.000 9 3 11 8 9 8 7 4 6 9 6 5 3 5 4 4 2 4 4 3 1 7 2 4 8 13 3 5 7 6 5 13 5 6 3 3	891 17 ^h 00 ^m S b 1.000 3 2 1 8 3 9 6 5 2 5 3 1 2 5 1 2 2 4 5 3 0 4 1 0 1 1 1 2 5 4 1 2 1 1 3 1	1615 17 ^h 20 ^m S h 1.047 1 1 1 1 0 0 0 0 1 0 1 0 1 0 0 0 0 1 1 0 0 0 1 0 0 2 1 0 0 0 1 0 3 1 1 3 2 0 1 1 1 1	534 17 ^h 40 ^m S a 0.914 0 0 0 1 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0	505 18 ^h 00 ^m S a 0.914 0 1 0 0 0 0 0 0 0 0 0 0 0

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										S h 0.740										S b 1.144										S e 0.781										W a 0.924									
δ = -10°										63 89 79 44 60 47										59 48 57 54 65 33										42 79 69 84 84 60										33 55 47 68 51 33									
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1231 13 ^h 20 ^m										463 13 ^h 40 ^m										1207 14 ^h 00 ^m										1584 14 ^h 20 ^m										828 14 ^h 40 ^m									
S f 1.090										S a 0.973										W e 0.937										S h 1.037										S b 1.022									
38 39 33 30 27 33										55 57 47 37 31 29										82 84 45 51 53 46										22 26 35 14 31 57										21 37 29 32 27 24									
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832 15 ^h 00 ^m										454 15 ^h 20 ^m										498 15 ^h 40 ^m										457* 16 ^h 00 ^m										869 16 ^h 20 ^m									
S b 1.273										S a 0.912										M a 1.163										S a 0.652										S b 1.017									
33 24 12 24 12 16										12 22 31 49 29 38										39 41 24 8 8 10										12 26 22 23 17 34										14 14 18 29 15 10									
24 22 18 43 25 36										32 16 30 65 30 41										8 42 35 20 26 29										22 28 41 25 38 23										23 23 20 26 17 11									
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9 11 17 21 17 13										20 24 20 21 18 6										9 19 33 17 14 17										26 21 27 28 33 22										16 14 11 11 11 9									
878 16 ^h 40 ^m										829 17 ^h 00 ^m										1623 17 ^h 20 ^m										1246 17 ^h 40 ^m										499 18 ^h 00 ^m									
S b 1.000										S b 1.000										W h 1.031										S f 1.084										S a 0.914									
5 13 16 7 4 5										0 1 1 0 4 5										0 2 1 0 0 3										1 0 0 0 0 0										1 1 1 0 0 0									
15 9 11 5 12 8										3 3 11 4 7 6										2 1 0 0 0 1										0 0 0 1 0 0										0 1 0 0 0 0									
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1211 13 ^h 20 ^m										1181 13 ^h 40 ^m										1203 14 ^h 00 ^m										849 14 ^h 20 ^m										822 14 ^h 40 ^m									
W e 0.977										W e 0.796										W e 0.732										S b 1.322										S b 0.804									
49 49 51 41 33 45										56 34 35 44 35 58										53 48 21 63 43 49										29 38 30 27 36 34										45 50 59 30 33 31									
43 67 85 56 47 50										37 27 24 22 61 46										61 63 51 52 40 43										14 43 15 26 20 33										76 106 55 47 35 36									
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39 34 34 39 27 32										43 91 47 46 36 32										72 69 53 62 38 50										29 31 14 28 16 37										40 38 56 52 21 29									
32 42 48 29 40 38										49 63 53 47 40 38										111 110 76 82 65 62										25 23 18 14 33 38										29 46 40 48 36 30									
442 15 ^h 00 ^m										474 15 ^h 20 ^m										508 15 ^h 40 ^m										464 16 ^h 00 ^m										872 16 ^h 20 ^m									
S a 0.979										S a 0.685										M a 0.846										M a 1.390										S b 1.056									
23 32 36 24 24 23										21 28 19 36 30 30										16 28 42 32 40 30										12 32 31 15 3 3										20 18 11 17 15 17									
33 28 18 40 49 53										38 34 34 25 28 57										2 11 17 33 57 24										16 25 16 7 4 1										11 15 9 23 7 14									
38 40 41 34 30 37										34 30 43 32 30 78										3 20 42 57 24 19										12 39 8 15 4 7										15 14 4 19 11 7									
41 65 43 32 32 54										47 43 29 47 30 70										45 37 30 27 40 28										18 32 10 9 14 19										11 4 7 9 5 9									
38 43 33 39 51 28										33 38 42 45 50 62										35 34 37 37 22 23										15 12 26 14 20 15										7 10 10 7 7 7									
36 50 41 52 26 13										38 39 59 54 52 57										25 43 31 16 18 13										0 21 13 18 7 11										13 15 12 9 9 2									
820 16 ^h 40 ^m										823 17 ^h 00 ^m										839 17 ^h 20 ^m										1274 17 ^h 40 ^m										509 18 ^h 00 ^m									
S b 1.583										S b 1.233										S b 1.000										S f 1.084										S a 0.914									
17 15 10 6 4 11										3 6 4 12 3 12										3 3 1 0 1 0										1 2 1 4 0 0										0 0 0 0 0 1									
7 9 7 7 4 8										3 4 3 5 6 9										1 2 1 2 0 0										0 1 1 1 0 1										0 0 0 0 0 0									
10 12 8 1 6 10										2 4 6 5 3 10										4 0 0 1 1 0										0 2 0 0 0 0										1 0 0 0 0 0									
8 8 3 5 10 3										6 7 4 6 6 5										0 1 1 0 1 5										0 1 1 0 0 0										1 0 0 1 0 1									
4 9 1 11 7 4										4 3 5 4 11 0										4 0 2 2 2 3										0 0 1 0 0 0										0 1 0 0 0 1									
9 15 5 13 6 5										2 6 5 4 5 3										1 1 0 4 4 1										0 0 0 0 0 0										0 0 0 0 0 0									

$\delta = 0^\circ$

792 12 ^h 00 ^m					821 12 ^h 20 ^m					441 12 ^h 40 ^m					444 13 ^h 00 ^m															
S b 0.769					W b 0.793					S a 1.053					S a 1.003															
δ = 0°	71	82	137	113	84	55	74	68	81	50	55	62	29	47	71	63	62	49	45	52	43	47	58	26						
	61	72	101	59	78	52	55	45	49	67	47	50	52	53	125	91	54	53	80	53	47	57	44	41						
	71	84	89	102	85	74	88	50	30	49	53	64	62	102	121	73	41	73	62	47	50	48	40	55						
	99	78	73	119	120	76	42	73	27	56	81	53	67	93	92	48	68	39	96	70	67	41	47	44						
	54	66	77	81	88	90	96	69	38	61	65	86	103	150	100	75	43	44	42	70	60	97	79	61						
	56	49	66	58	59	55	63	68	65	64	45	58	64	66	51	61	33	26	45	66	124	94	48	37						
480 13 ^h 20 ^m					1234 13 ^h 40 ^m					1247 14 ^h 00 ^m					793 14 ^h 20 ^m					825 14 ^h 40 ^m										
S a 0.714					W f 1.534					S f 0.990					S b 0.820					S b 1.331										
84	62	59	47	53	57	60	25	48	59	31	28	43	26	29	28	18	59	92	50	64	62	109	56	24	27	27	33	36	44	
108	110	117	74	76	74	32	38	24	24	32	39	74	36	36	43	26	35	88	79	74	74	100	80	25	22	39	27	37	49	
80	107	131	82	80	74	30	26	39	28	45	26	69	48	34	28	27	41	91	91	61	48	79	68	38	38	27	35	38	52	
91	72	99	172	126	108	21	22	29	41	33	20	82	82	67	23	43	29	65	73	75	74	101	97	36	42	25	35	55	35	
121	98	76	87	66	51	27	37	22	36	32	72	41	59	37	41	30	37	87	110	63	46	59	36	44	40	32	41	61	43	
59	61	62	57	57	35	35	23	19	21	16	32	29	41	28	55	27	38	44	51	45	52	47	25	19	30	42	21	23	24	
492 15 ^h 00 ^m					445 15 ^h 20 ^m					481 15 ^h 40 ^m					491 16 ^h 00 ^m					1248 16 ^h 20 ^m										
S a 0.875					S a 0.956					Ma 1.500					S a 0.676					S f 1.169										
63	47	43	59	40	30	30	62	55	82	68	46	16	20	25	33	40	27	36	60	49	60	41	20	16	24	24	17	19	22	
97	83	58	55	52	47	60	75	62	66	67	67	7	12	12	26	14	28	51	87	21	24	22	20	15	8	16	24	25	16	
74	65	40	49	35	46	87	61	34	34	51	48	14	38	24	23	7	48	71	68	46	47	33	50	27	19	15	32	22	38	
46	60	37	30	54	51	32	42	26	37	51	31	18	39	33	30	29	41	44	55	62	52	40	25	27	19	24	12	11	20	
40	71	46	44	52	55	31	30	21	22	30	18	10	7	9	22	15	23	57	37	36	30	49	16	27	12	16	21	17	28	
20	25	37	27	17	20	20	16	14	26	38	26	5	20	17	16	24	16	31	50	28	15	11	4	19	10	13	20	15	16	
876 16 ^h 40 ^m					836 17 ^h 00 ^m					521 17 ^h 20 ^m					1275 17 ^h 40 ^m					514 18 ^h 00 ^m										
S b 0.733					S b 0.891					S a 0.914					S f 1.084					S a 0.914										
21	14	12	12	9	15	22	26	34	31	23	26	2	1	5	6	6	3	2	0	1	2	6	3	0	0	0	3	1	3	0
20	15	6	24	13	11	25	20	18	35	36	18	2	2	5	0	4	6	3	2	0	1	3	0	1	1	1	1	2	1	
24	16	10	17	21	19	16	9	13	13	14	13	0	3	8	7	2	6	1	0	0	6	0	0	0	0	0	0	0	2	2
30	27	33	16	22	27	11	6	2	7	6	13	2	3	7	14	6	9	0	0	0	0	2	1	1	0	1	2	2	1	
33	30	40	20	32	34	5	8	7	19	41	8	3	6	7	18	7	2	2	3	4	1	2	0	0	0	0	1	0	1	1
30	25	23	16	22	29	4	8	12	8	5	16	2	4	0	2	1	2	1	3	1	0	1	0	0	0	0	0	0	1	0

 $\delta = +5^\circ$

758 12 ^h 00 ^m					824* 12 ^h 20 ^m					816 12 ^h 40 ^m					467 13 ^h 00 ^m									
Wb 1.066					S b 1.217					Wb 0.792					S a 0.814									
58 37 42 40 42 76					41 63 70 54 50 39					63 81 48 45 54 72					87 79 101 82 58 51									
89 67 43 54 56 74					95 84 65 91 63 64					83 53 49 118 94 98					93 69 97 64 62 64									
80 62 44 56 89 100					90 66 76 127 121 65					88 97 53 62 71 119					136 64 75 89 78 84									
49 40 94 39 73 85					60 41 105 68 93 47					106 75 69 93 101 98					101 71 103 66 66 105									
46 36 40 61 47 60					87 72 78 69 93 53					72 49 90 104 63 105					82 83 96 61 94 53									
45 51 94 73 52 36					43 48 59 36 38 41					53 55 98 83 83 76					52 61 51 39 61 27									
1232 13 ^h 20 ^m					1236 13 ^h 40 ^m					1216 14 ^h 00 ^m					819 14 ^h 20 ^m					835 14 ^h 40 ^m				
W f 1.229					S f 0.911					S e 1.112					S b 1.106					S b 1.021				
39 33 25 37 89 27					65 58 65 50 34 53					40 55 61 41 56 46					45 55 38 41 51 41					41 50 48 41 42 54				
34 25 47 40 41 55					50 53 47 54 56 28					61 88 89 54 68 38					48 66 93 75 57 59					46 42 35 52 65 54				
50 28 35 50 55 76					112 64 40 54 29 40					101 76 48 58 68 95					96 58 76 73 115 78					82 41 28 52 55 60				
29 22 24 35 44 52					50 63 84 86 48 36					24 34 39 36 54 30					85 74 71 57 74 38					48 46 69 52 56 61				
31 26 34 43 34 41					43 69 80 71 64 40					52 39 46 47 48 27					79 99 55 37 60 67					89 55 77 122 84 87				
71 46 37 41 37 39					79 39 65 106 65 49					42 18 31 25 18 55					58 47 54 63 90 45					33 31 36 35 38 48				
817 15 ^h 00 ^m					448 15 ^h 20 ^m					815* 15 ^h 40 ^m					1182 16 ^h 00 ^m					1217 16 ^h 20 ^m				
S b 0.811					S a 1.151					S b 0.734					S e 0.884					S e 0.966				
165 126 90 43 27 33					48 66 96 90 113 83					32 41 75 92 63 77					11 19 14 19 18 13					25 39 29 19 15 14				
198 115 63 44 67 64					47 63 69 85 82 112					62 66 50 85 54 72					29 41 20 48 65 47					24 36 40 27 26 17				
243 108 119 81 95 104					63 85 91 114 124 161					45 39 68 59 55 91					33 35 50 42 26 33					27 32 32 27 33 29				
256 96 59 52 47 52					78 118 123 213 199 177					53 45 69 55 62 86					48 33 30 27 33 41					25 17 36 16 16 31				
148 123 63 61 70 93					55 96 56 111 87 75					24 38 48 95 44 61					31 55 31 28 26 17					23 37 38 24 14 15				
94 59 55 49 54 24					31 51 55 68 51 44					23 25 41 48 53 34					25 40 33 57 29 17					19 25 36 19 21 16				
1585 16 ^h 40 ^m					1229 17 ^h 00 ^m					1257 17 ^h 20 ^m					842 17 ^h 40 ^m					913 18 ^h 00 ^m				
S h 1.146					S f 1.050					S f 1.099					S b 1.060					S b 1.000				
12 13 11 23 27 20					7 8 8 12 7 16					8 9 6 7 15 4					4 10 9 9 6 10 4					4 2 3 2 2 1				
10 28 18 18 33 15					12 8 9 11 12 13					15 15 13 12 21 20					10 7 5 7 15 18					2 6 1 3 1 6				
12 11 11 19 18 16					15 6 13 7 14 10					10 6 11 7 5 11					7 5 10 5 14 6					2 2 2 2 2 3				
28 15 16 17 11 13					11 17 15 7 12 26					3 3 5 7 6 10					4 4 8 10 5 2					3 4 4 1 0 2				
20 13 13 16 6 14					14 13 14 16 11 16					5 10 3 3 0 3					3 4 3 5 1 2					2 0 1 3 4 0				
12 18 7 9 12 10					11 9 14 13 17 11					4 4 2 6 5 4					0 1 4 2 6 5					5 1 4 4 3 3				

$\delta = +10^\circ$

										1149 12 ^h 00 ^m										1140 12 ^h 20 ^m										831 12 ^h 40 ^m										471 13 ^h 00 ^m																			
										S e 1.016										S e 0.814										S b 1.118										W a 0.742																			
δ = +10°										60	69	47	42	41	79	115	130	111	125	89	69	33	31	80	64	55	57	92	78	78	69	37	47	114	83	115	59	59	55	63	104	70	56	68	92														
										65	110	66	51	123	73	108	129	64	68	63	71	27	53	61	61	65	72	114	83	115	59	59	55	63	104	70	56	68	92	101	176	128	101	74	86														
										71	98	99	93	85	51	122	108	103	75	78	70	52	45	69	70	81	80	63	104	70	56	68	92	101	176	128	101	74	86	106	118	122	89	105	113														
										75	46	49	48	61	65	104	153	113	82	71	92	87	43	70	73	71	89	101	176	128	101	74	86	106	118	122	89	105	113	63	58	77	69	39	44														
										51	46	37	37	29	58	75	136	99	136	102	69	64	61	79	51	62	44	106	118	122	89	105	113	63	58	77	69	39	44	47	71	51	46	57	35														
										68	47	50	39	42	49	55	73	96	65	62	58	47	71	51	46	57	35	63	58	77	69	39	44	47	71	51	46	57	35																				
										1508 13 ^h 20 ^m										1238 13 ^h 40 ^m										1249 14 ^h 00 ^m										1597 14 ^h 20 ^m										1592 14 ^h 40 ^m									
										S h 1.092										W f 1.083										S f 0.954										S h 0.882										S h 1.078									
47	103	48	52	52	43	59	59	47	46	32	50	97	93	88	69	68	65	70	69	42	32	46	50	44	55	43	78	52	41	67	154	72	51	31	47	86	94	65	77	74	84																		
95	132	92	122	61	59	57	51	51	58	57	78	85	92	68	47	68	60	73	106	61	40	62	86	67	154	72	51	31	47	86	94	65	77	74	84	90	95	86	84	89	73																		
104	70	52	62	53	50	48	34	37	59	64	78	49	100	84	75	53	47	86	54	31	31	43	29	86	94	65	77	74	84	90	95	86	84	89	73	66	52	78	66	63	59																		
69	64	39	49	79	54	83	63	40	58	45	54	60	66	117	71	42	78	98	39	59	72	75	52	66	52	78	66	63	59	49	45	56	39	53	50	83	63	40	58	45	54	60	66	117	71	42	78												
48	66	76	62	73	45	61	59	40	31	53	36	76	81	37	60	48	37	87	62	39	52	157	91	66	52	78	66	63	59	49	45	56	39	53	50	83	63	40	58	45	54	60	66	117	71	42	78												
55	40	30	40	77	38	79	70	75	57	40	55	54	71	52	34	60	34	87	113	56	67	68	67	49	45	56	39	53	50	83	63	40	58	45	54	60	66	117	71	42	78	98	39	59	72	75	52												
										838 15 ^h 00 ^m										472 15 ^h 20 ^m										1255 15 ^h 40 ^m										1235 16 ^h 00 ^m										1224 16 ^h 20 ^m									
										S b 0.912										S a 1.069										S f 1.069										S f 1.448										S f 0.916									
47	56	48	69	66	51	27	26	28	34	35	24	44	46	16	35	49	25	22	33	33	23	34	31	36	27	17	29	45	23	25	27	23	19	42	22	46	61	37	47	35	37	47	35	37	47	35	37												
62	58	72	72	61	64	31	42	51	34	40	60	25	40	48	28	31	27	25	27	23	19	42	22	46	61	37	47	35	37	47	35	37	47	35	37	47	35	37	47	35	37	47	35	37	47	35	37												
47	83	82	58	41	75	57	52	63	43	56	36	47	45	41	36	47	46	21	17	12	33	16	39	38	39	36	56	34	24	59	86	93	66	127	59	46	41	63	42	33	46	65	72	91	60	50	40												
59	86	93	66	127	59	46	41	63	42	33	46	65	65	50	19	40	27	18	16	18	21	27	36	31	37	76	47	28	21	80	155	130	55	48	47	51	77	133	120	73	48	65	72	91	60	50	40												
80	155	130	55	48	47	51	77	133	120	73	48	65	72	91	60	50	40	15	30	29	19	12	17	38	102	51	26	25	31	20	20	19	23	20	23	8	4	8	9	9	7	9	6	10	4	6	4												
153	137	71	32	22	31	53	74	87	95	112	86	17	24	43	58	31	47	8	10	9	10	8	6	24	48	32	26	16	11	20	20	19	23	20	23	8	4	8	9	9	7	9	6	10	4	6	4												
										1270 16 ^h 40 ^m										881 17 ^h 00 ^m										524 17 ^h 20 ^m										1621 17 ^h 40 ^m										915 18 ^h 00 ^m									
										S f 1.024										S b 1.469										S a 1.112										S h 1.060										S b 1.168									
20	20	19	23	20	23	2	11	10	9	13	9	4	15	4	8	4	4	6	7	8	9	10	1	6	6	13	3	6	2	18	22	17	18	21	14	6	9	13	11	8	12	4	9	4	14	12	6												
24	24	38	53	25	30	8	18	15	10	6	4	12	6	4	14	14	13	4	6	10	17	5	4	2	12	5	2	2	1	11	21	21	16	18	23	6	2	7	8	7	4	8	14	19	29	20	6												
10	18	26	30	19	19	6	18	15	10	6	4	12	6	4	14	14	13	4	6	10	17	5	4	2	12	5	2	2	1	11	21	21	16	18	23	6	2	7	8	7	4	8	14	19	29	20	6												
15	9	12	17	26	13	4	7	8	7	5	6	6	8	8	9	17	4	7	6	13	10	6	6	2	0	2	2	5	0	20	20	19	23	20	23	8	4	8	9	9	7	9	6	10	4	6	4												

 $\delta = +15^\circ$

δ = +15°		1132 12 ^h 00 ^m										1136 12 ^h 20 ^m										449 12 ^h 40 ^m										473 13 ^h 00 ^m																			
		S e 0.752										S e 0.831										S a 1.106										W a 0.890																			
		73	59	65	56	55	55	64	75	89	67	56	43	37	53	47	68	66	40	67	52	54	43	38	44																										
		79	63	54	61	60	58	116	68	86	72	78	89	30	38	56	86	128	58	63	75	38	50	32	39																										
		120	113	63	85	70	101	62	57	54	54	62	101	29	51	33	52	76	39	85	62	56	55	29	36																										
		157 81 75 56 44 63										49 46 53 71 98 101										45 35 41 77 67 49										101 113 59 36 48 73																			
		150 116 86 96 111 125										65 75 91 114 101 120										39 68 50 73 57 52										78 98 53 53 57 55																			
		77 94 60 55 81 81										107 205 135 125 92 74										33 26 64 49 44 54										53 44 59 50 30 25																			
		1515 ^{**} 13 ^h 20 ^m										1240 13 ^h 40 ^m										1251 14 ^h 00 ^m										847** 14 ^h 20 ^m										1555 14 ^h 40 ^m									
		S h 1.012										W f 1.148										W f 1.243										S b 1.917										S h 0.972									
		36	68	62	60	53	46	47	56	55	52	42	25	29	50	45	44	42	60	56	78	89	52	40	26	126	88	46	87	89	49																				
		57	77	46	75	44	58	63	56	51	44	43	37	52	57	101	63	67	46	39	96	65	25	28	40	136	82	87	60	107	39																				
		33	38	53	68	51	45	82	46	47	62	43	22	52	91	95	98	62	76	39	60	38	29	30	24	72	88	80	99	88	66																				
		84 73 120 70 70 57										117 61 64 62 53 70										60 70 73 61 90 90										53 47 32 29 28 26										59 95 78 107 80 59									
		94 83 111 56 55 57										74 50 53 32 47 85										43 64 56 65 62 82										35 46 29 28 28 12										62 95 114 108 43 52									
		46 91 46 65 54 43										65 66 54 55 50 59										52 65 72 41 56 55										28 23 13 12 14 14										60 78 58 84 55 37									
		496 15 ^h 00 ^m										477 15 ^h 20 ^m										1617 15 ^h 40 ^m										1237 16 ^h 00 ^m										1250 16 ^h 20 ^m									
		S a 0.951										S a 0.815										S h 1.126										S f 1.078										S f 1.004									
		85	68	66	51	64	127	27	36	28	21	58	71	20	34	66	37	22	18	53	63	175	53	41	25	32	44	47	43	19	42																				
		87	85	77	88	89	136	24	45	46	28	70	67	33	42	34	49	32	19	30	64	238	105	55	25	30	41	35	55	46	36																				
		79	50	52	50	43	66	50	52	46	55	86	73	21	34	48	27	23	23	50	87	149	97	33	16	23	63	46	51	59	44																				
		53 62 47 51 38 74										33 45 35 55 56 48										25 37 37 33 32 25										64 68 94 42 20 16										45 88 98 67 48 63									
		52 53 47 53 42 46										57 40 53 56 39 51										46 25 37 48 28 24										29 51 44 30 28 30										86 73 66 52 49 37									
		23 42 37 61 67 33										36 39 39 55 51 29										41 40 25 35 43 22										32 41 53 40 31 42										42 37 31 30 49 34									
		873** 16 ^h 40 ^m										856 17 ^h 00 ^m										497 17 ^h 20 ^m										1273 17 ^h 40 ^m										1280 18 ^h 00 ^m									
		S b 2.839										W b 0.790										S a 0.808										S f 1.231										S f 0.914									
		12	5	6	3	13	3	18	9	9	18	22	23	23	13	18	12	10	16	13	23	25	31	15	12	2	9	6	9	6	15																				
		8	13	19	7	7	11	18	19	21	17	20	26	27	20	21	17	13	19	15	18	31	18	10	11	6	18	5	4	9	25																				
		4	8	8	18	2	12	15	14	22	29	15	15	23	20	14	9	10	14	9	24	21	16	15	11	8	7	11	9	11	17																				
		12 4 29 9 6 11										9 24 23 17 17 24										14 22 28 9 7 7										24 23 17 13 27 10										13 7 8 14 13 17									
		11 9 12 21 18 25										25 28 35 26 25 29										9 16 18 17 11 12										6 14 12 7 16 7										15 4 10 13 17 10									
		15 6 14 9 11 13										12 14 15 17 11 16										10 14 16 11 9 10										5 11 9 3 7 6										6 9 8 9 14 3									

$\delta = +20^\circ$

751 12 ^h 00 ^m										757* 12 ^h 20 ^m										837 12 ^h 40 ^m										840 13 ^h 00 ^m																			
S b 1.182										S b 1.113										Wb 1.017										S b 0.927																			
67 70 97 72 76 77										33 44 55 75 97 46										32 32 33 26 33 30										55 45 35 29 37 31																			
66 48 85 98 89 119										53 29 67 55 67 49										25 28 40 42 36 42										61 65 33 37 19 19																			
63 42 142 76 36 106										57 42 76 61 63 53										42 43 32 22 44 51										65 70 65 41 51 39																			
74 51 59 45 50 50										48 52 43 77 84 53										83 58 35 66 32 48										86 85 116 103 89 52																			
55 49 50 54 55 47										39 62 59 34 67 53										67 44 38 127 39 45										71 83 109 87 69 63																			
48 42 43 39 41 39										39 59 61 52 51 40										36 40 54 76 63 57										50 47 43 36 38 43																			
1524 13 ^h 20 ^m										1566 13 ^h 40 ^m										1577 14 ^h 00 ^m										1253* 14 ^h 20 ^m										1591 14 ^h 40 ^m									
S h 1.179										S h 0.906										S h 0.964										Wf 1.390										S h 0.916									
37 58 69 74 51 52										78 51 51 44 48 28										54 51 42 66 95 62										40 24 35 27 21 27										119 110 118 97 82 63									
31 43 61 68 51 46										82 51 48 63 41 24										75 55 54 58 92 53										32 41 36 43 30 44										107 95 54 86 67 66									
35 39 36 47 56 33										74 39 66 51 42 43										90 52 41 83 91 54										46 51 47 25 41 56										82 97 91 78 64 76									
50 55 52 35 33 66										93 87 68 42 37 39										95 103 57 58 91 75										53 47 51 33 52 79										73 75 107 87 76 77									
59 50 56 41 42 44										78 155 135 116 63 70										86 70 54 57 72 70										57 44 35 89 60 63										134 99 58 68 95 52									
31 53 57 48 31 34										80 97 96 66 59 38										44 63 76 69 57 60										78 86 103 59 46 39										118 93 42 78 85 57									
1571 15 ^h 00 ^m										1560 15 ^h 20 ^m										506 15 ^h 40 ^m										1239 16 ^h 00 ^m										1262 16 ^h 20 ^m									
S h 1.200										S h 1.037										S a 0.869										S f 1.075										Wf 0.989									
36 53 39 50 70 61										37 38 31 52 42 32										51 38 53 83 76 62										39 37 39 46 25 37										40 30 39 42 23 52									
38 58 86 85 64 60										51 48 55 58 29 31										67 53 42 114 74 59										45 35 47 52 41 56										80 54 50 53 44 54									
58 89 80 50 63 48										30 32 72 58 56 55										74 56 40 39 42 23										36 30 71 70 66 64										71 61 60 50 46 42									
75 69 41 80 73 55										31 41 70 58 65 75										91 111 38 61 44 49										29 47 64 71 60 53										52 44 41 48 76 38									
109 46 36 41 103 90										44 56 40 35 69 96										86 82 52 65 39 38										49 76 151 119 91 38										41 31 38 59 41 42									
66 53 39 37 34 80										32 39 32 21 47 67										34 39 60 50 22 19										70 114 192 78 45 30										18 31 39 37 28 55									
848 16 ^h 40 ^m										519 17 ^h 00 ^m										833 17 ^h 20 ^m										1272** 17 ^h 40 ^m										507 18 ^h 00 ^m									
Wb 1.008										S a 0.865										S b 1.179										S f 2.310										S a 0.940									
41 21 25 30 34 34										36 33 32 36 33 22										19 21 23 18 13 21										9 9 5 8 6 9										9 18 9 10 11 4									
27 19 27 15 27 48										10 40 41 19 25 38										15 16 20 23 25 21										7 4 3 7 7 5										35 18 22 10 16 11									
32 33 27 27 21 36										24 32 19 30 22 30										31 24 22 19 28 19										8 6 7 6 6 6										7 11 26 14 12 14									
35 17 25 33 26 38										30 32 23 22 33 15										18 37 32 21 18 11										7 4 9 8 7 9										3 5 13 14 17 7									
39 26 28 22 29 38										20 36 35 30 41 7										34 19 15 21 20 10										10 6 7 9 5 5										16 3 6 10 33 14									
44 33 28 10 27 20										17 10 11 16 24 29										19 18 14 10 7 13										10 17 7 11 11 2										8 9 9 8 4 15									

west-east direction. The only exception to this procedure was that Mayall counted the strips alternately from west to east and from east to west. There are 1296 separate counts recorded for each plate. The 36 counts in each square degree are combined to give the tabular values.

It is of the greatest importance to maintain a uniform standard for the identification of nebulae. This requirement is particularly difficult since by far the most numerous nebulae lie near the limit of detection. It would be possible to stop the counts somewhat above the limiting magnitude, but this procedure would necessitate estimating whether each nebula fell above or below the standard brightness. Due to the great variety of nebular forms, sizes and surface brightness, this process would be very uncertain. It was accordingly decided to count every nebula that could be identified as such with reasonable probability. It is obvious that the limiting magnitude will not be the same for all nebular types. A fairly bright but small elliptical nebula may fail to be distinguished from a star. On the other hand a large nebula of extremely low surface brightness may escape detection though its total apparent magnitude is well above the normal limit. Thus for certain types of nebulae the limit is no doubt fainter than 18.4 mag. while, for

others it is brighter than this value. The value 18.4 mag. is an average limit derived from comparing our counts with those of Hubble, and it refers to the scale of magnitudes that he used.

On some plates the number of defects resembling nebulae introduces an exasperating element of uncertainty. Little can be done to avoid errors in identification beyond relying on judgment and experience. To duplicate the plates and the counts would extend the program beyond practical limits.

IV. CORRECTIONS TO THE COUNTS

In order to reduce the data to a reasonably homogeneous system, it is necessary to apply several corrections.

Off-axis correction. Due to vignetting and to some inferiority of the images at considerable distances from the optical axis there is a decrease in the number of nebulae counted with increasing distance from the center of the plate. To correct for this effect, the numbers of nebulae in each of the thirty-six square degrees were added for all the plates in Area III. The counts were again summed for all square degrees at the same distance from the plate center, and a smooth curve was drawn through these sums plotted against the distance. The reciprocals of these ordinates

are proportional to the off-axis corrections. Finally, the factor of proportionality was chosen so as to make the off-axis correction factor unity at the plate center. This "stacking" process was based on a total count in Area III of 210980 nebulae.

East-west effect. For some unexplained reason fewer nebulae are counted west of a plate center than east of it. This effect was found consistently in the counts by both Shane and Wirtanen and also in Mayall's counts which were made in alternate rows east and west. A number of suggestions to explain this puzzling phenomenon have been offered. To test any one of them adequately would require so large an amount of work that it would delay unduly the main program. It was therefore thought best to postpone an investigation of this effect.

To calculate the east-west correction, the number of nebulae in the overlapping regions of all plates were compared, except in cases where less than 30 nebulae occurred in an overlap. From a study of the plates in Area III, it was found that in a field $2\frac{1}{2}^\circ$ east of a plate center, 1.236 times as many nebulae are recorded as in the same field counted $2\frac{1}{2}^\circ$ west of the center on the overlapping plate. There is no corresponding north-south effect. This result has been checked in Area V from $\alpha = 0^h$ to $\alpha = 6^h$ and from $\delta = +20^\circ$ to $\delta = +60^\circ$. Here the east-west factor is 1.231, and again there is no certain evidence of a north-south effect.

In correcting for the east-west effect, the assumption is made that the logarithm of the correction factor varies linearly across the plate with a value of zero at the center. The factors thus derived were combined with the off-axis corrections to form a table of "field corrections." The nebular count in each square degree was accordingly multiplied by the appropriate tabular number.

TABLE II. FIELD CORRECTION FACTORS

		North					
East	1.10	1.03	1.02	1.06	1.17	1.36	
	0.99	0.95	0.98	1.02	1.08	1.22	
	0.94	0.94	0.98	1.02	1.07	1.16	
	0.94	0.94	0.98	1.02	1.07	1.16	
	0.99	0.95	0.98	1.02	1.08	1.22	
	1.10	1.03	1.02	1.06	1.17	1.36	

Atmospheric extinction. Corrections were made for atmospheric extinction to reduce the counts to their probable zenith values. This correction is simplified by the circumstance that all exposures were centered on the meridian, and to a sufficient approximation, therefore, the extinc-

tion factor depends only on δ . A value for the photographic extinction in the zenith of 0.30 mag., supplied by Kron, was used. The logarithm of the correction factor is accordingly equal to

$$0.60 \times 0.30 (\sec z - 1),$$

where 0.60 is the logarithm of the factor by which the number of nebulae increases per unit of limiting magnitude, on the assumption of a uniform distribution in depth, and z represents the average zenith distance of the region during the exposure. The extinction factor is read from a curve as a function of δ . The factor varies from 1.00 in the zenith to 1.53 at $\delta = -22^\circ 5$.

Effective exposure time. Eight plates were estimated to be deficient in exposure time mostly because of haze or clouds. It was assumed that a factor of three in the exposure time corresponds to a unit change in limiting magnitude. An exposure of 100 minutes, the minimum accepted, requires that the counts be corrected by a factor of 1.26 to reduce them to the standard 120 minute exposure.

Emulsion factor. Five different emulsions were used for the plates in Area III, and as these varied slightly in sensitivity, an appropriate emulsion factor was applied in each case. The emulsion factors and the personal factors were derived together from a least-squares solution, which is discussed in detail in the next section.

Personal factor. All except five of the plates in this area were counted by the authors. Personal factors were applied to reduce Wirtanen's and Mayall's counts to the standard of the senior

Figure 1. Plate notation.

author. The following method was used in determining this factor and the emulsion factor.

To explain the notation reference is made to Figure 1, which represents a particular photograph with its four overlapping plates. The over-

lap regions are the four long rectangles including the corner squares, so that each corner is included twice.

Let

ν_m^0 = the true number of nebulae in overlap m to the standard limiting magnitude,

ν_m, ν_m' = numbers of nebulae counted in m on plates P_0 and P_m' , respectively,

$\alpha_m = \alpha_m'$ = average off-axis correction for region m on P_0 and P_m' , respectively,

q = east-west factor,

$\beta_m = \beta_m'$ = average extinction correction for region m ,

i_0, i_m' = exposure deficiency factors for P_0 and P_m' , respectively,

ϵ_0, ϵ_m' = emulsion factors for P_0 and P_m' , respectively,

p_0, p_m' = personal factors for P_0 and P_m' , respectively.

$$\rho_m = \frac{\nu_m'}{\nu_m}.$$

Then

$$\nu_1 = \frac{\nu_1^0}{\alpha_1 \beta_1 i_0 \epsilon_0 p_0 q},$$

$$\nu_1' = \frac{\nu_1^0 q}{\alpha_1' \beta_1' i_1' \epsilon_1' p_1'}.$$

Whence

$$\rho_1 = \frac{i_0 \epsilon_0 p_0 q^2}{i_1' \epsilon_1' p_1'},$$

or

$$\log \rho_1 + \log i_1' - \log i_0 - \log q^2 = \log \epsilon_0 - \log \epsilon_1' + \log p_0 - \log p_1'.$$

The corresponding equation for $m = 2$ has the same form except that q^2 is replaced by $1/q^2$. For $m = 3$ and $m = 4$ the q^2 term does not occur. In the solution, however, only equations for $m = 1$ and $m = 3$ are used since the observational material in $m = 2$ and $m = 4$ appears in $m = 1$ and $m = 3$ when P_2' and P_4' are adopted as P_0 . The left-hand members of the equations are known quantities. When we replace ϵ_0 and ϵ_m' by the emulsion factors appropriate to the particular plates, four unknown emulsion factors $\epsilon_a, \epsilon_b, \epsilon_f$, and ϵ_h appear in the equations. $\epsilon_b = 1$ was adopted as standard so that $\log \epsilon_b = 0$. Similarly the personal factors p_w and p_m corresponding to Wirtanen and Mayall are unknowns,

with the factor for Shane taken as standard. The plates counted by Mayall were too few to justify inclusion in the general solutions. After the other constants were determined, p_m was calculated from the 12 equations in which it appeared. In the general solution no equation was included if either ν_m or ν_m' was less than 30.

A least-squares solution was made from the 261 resulting equations. The constants together with their probable errors are included in Table III.

TABLE III. PLATE CONSTANTS

	log	number	
ϵ_a	$-0.039 \pm .009$	0.914	Standard
ϵ_b	0.000	1.000	
ϵ_c	$-0.056 \pm .014$	0.879	
ϵ_f	$+0.035 \pm .011$	1.084	
ϵ_h	$+0.020 \pm .012$	1.047	
p_s	0.000	1.000	Standard
p_w	$-0.007 \pm .008$	0.984	
p_m	$+0.103 \pm .034$	1.268	

The ratio of the extremes of the emulsion factors is 1.234. This value corresponds to the surprisingly small range in limiting magnitude of 0.15 mag. The large value of p_m probably reflects a certain degree of conservatism in Mayall's identification of objects as nebulae.

Accidental errors. The counts on each plate are subject to a further source of error that may be treated as accidental in character. It is the compounded effect of seeing, night-to-night fluctuations in atmospheric transmission, variation of plate sensitivity within a given emulsion, non-uniformity in processing the plates, and irregular changes in the personal counting factors. In addition to these sources of variation, there may be others of a more obscure nature. The best that can be done to determine the "accidental factor" is to adopt a smoothing process based on the overlaps.

Let f_1, f_m' = the accidental factors for plates P_0 and P_m' , respectively. Then for $m = 1$

$$\nu_1 = \frac{\nu_1^0}{\alpha_1 \beta_1 i_0 \epsilon_0 p_0 q} \frac{1}{f},$$

$$\nu_1' = \frac{\nu_1^0 q}{\alpha_1' \beta_1' i_1' \epsilon_1' p_1'} \frac{1}{f_1'},$$

whence

$$f = f_1' \rho_1 \left[\frac{i_1' \epsilon_1' p_1'}{i_0 \epsilon_0 p_0} \frac{1}{q^2} \right].$$

Let the factor in brackets be called g_1' . Expressions for g_2', g_3', g_4' are the same except that g_2' has q^2 in the numerator instead of the denominator while in g_3' and g_4' , q^2 is replaced by unity.

We thus have n equations for f of the form

$$f = f_m' \rho_m g_m',$$

where n is normally 4 but may be less if any of the plates P_m' are not used. These equations determine f in terms of f' . In addition we should use the equation $f = 1$ to give appropriate weight to P_0 . If we multiply the $n + 1$ equations together we get

$$f^{n+1} = \prod_n f_m' \rho_m g_m'.$$

The smoothing process depends on the assumption that $\prod_n f_m' = 1$. Thus

$$f = [\prod_n f_m' \rho_m g_m']^{1/(n+1)}.$$

If the plate P_0 is of such low weight that its accidental factor, f , should be determined solely from its neighbors, we replace the exponent $1/(n+1)$ by $1/n$, i.e., we omit the equation $f = 1$. In Area III there were seven plates that for one reason or another were omitted in calculating the constants and the f 's. All but one were strongly deficient in numbers of nebulae as compared with the numbers in their overlaps. In most cases this effect was verified by an examination of the star images. A single plate ($\alpha = 14^h 20^m$, $\delta = -20^\circ$) showed a great excess of nebulae. The reason is not known but it was thought desirable to omit this plate in determining the constants.

No overlap was used in calculating f if ρ_m depended on ν_m or ν_m' less than 30. In and near the zone of avoidance this was the usual situation, so that for many plates, f was taken equal to unity.

A study of the f factors reveals that their logs are distributed about zero in an approximately normal manner with a slight excess of large and small values. The probable departure of $\log f$ from zero is ± 0.055 .

Let us designate by F the complete plate factor for P_0 . This quantity equals f multiplied by the exposure, emulsion and personal factors.

Thus

$$F = f i_0 \epsilon_0 p.$$

The value of F calculated for each plate is included in Table I.

The reduction of the counts requires first that the field and extinction factors shall be applied for each square degree on a plate, and that these

values shall then be multiplied by the appropriate F . After these corrections have been applied to the counts, the material is ready for discussion.

V. THE PROBABLE ERRORS

The comparison of corrected counts in the same square degree on overlapping plates provides material for calculating the probable errors. Only the northwest quarter of Area III was used since it contains sufficient data for a solution, and it is the region of greatest nebular density. The logarithm of the ratio of counts in overlapping regions was formed from 510 comparisons. The resulting probable error in the logarithm of the nebular count per square degree is 0.054 which corresponds to ± 12.5 per cent of the number of nebulae. The probable error in the logarithm applies to counts in the more populous area, and it should obviously be larger in areas of low nebular density. The distribution of residuals closely follows a normal error curve. An application of the χ^2 test showed that the probability of a poorer fit than that obtained is 0.40.

The errors arise from several sources, the most important of which appear to be:

1. The plate factors, F , are not determined with complete accuracy because they depend on a smoothing process that reduces but does not eliminate the individual plate errors.
2. The limiting magnitude is not necessarily constant over a given plate but varies with any non-uniformity of emulsion sensitivity and with dark-room processing.
3. Some nebulae may be overlooked in counting while certain plate defects may be recorded as nebulae.
4. In counting near the limit of detectability the observer cannot maintain a uniform standard of identification.

If all the discrepancies among the counts were assigned to variations in emulsion sensitivity alone, they could be accounted for by a probable error in the sensitivity of only 0.09 mag. A variable plate sensitivity cannot, of course, bear the entire responsibility, and its effect may well be equaled or exceeded by one or more of the other sources of error. If this conjecture is correct, the observations indicate a rather remarkable uniformity of emulsion coating over a one-degree border around the large plates.

Figure 2. Equal surface density contours for nebulae in Area III, based on sm

Figure 2. Equal surface density contours for nebulae in Area III, based on smoothed counts by 1° squares.

ae in Area III, based on smoothed counts by 1° squares.

VI. THE CONTOUR MAP

The general features of the nebular distribution are probably best portrayed by means of a contour map showing curves of equal surface density. In drawing the contours it is not feasible to use the individual reduced counts by square degrees. For one reason, the variation in numbers of nebulae between adjacent square degrees is so irregular that excessively complicated contours would be required. Moreover, the probable errors of the counts are of such size that in many cases this complicated detail would be misleading. It was therefore decided to form running means of four square degrees and to base the map on these values. Every combination of four square degrees having a common corner was averaged, and the results were entered on a chart at the position of the corner. The contour map, Figure 2, was drawn from these data. The contour interval is ten nebulae per square degree, with the contours 20, 60, 100, 140, etc. drawn in heavy lines. In addition the contours representing 5 and 15 nebulae per square degree are indicated by broken lines. Completely enclosed areas of lower density are shown by hachures on the lowest contours of such areas. The process of smoothing by fours obviously conceals some detail and suppresses the relief to a certain extent. For example, if we consider the three great clouds of nebulae that lie between galactic latitudes $b = +40^\circ$ and $+50^\circ$, the maximum contours are 180, 220, and 160, whereas the most populous square degrees contain 244, 272, and 258 nebulae, respectively. The two strongly deficient areas at galactic longitude $l = 212^\circ$, $b = +34^\circ$ and at $l = 333^\circ$, $b = +35^\circ$ each have minimum contours of 10, whereas the minimum numbers of nebulae are 7 and 2, respectively. The actual relief is thus greater than is indicated by the map.

Individual nebulae on the low density side of the number 5 contour are indicated by small circles. The open circles represent nebulae that have a strong appearance of reality but were observed on only one plate. Nebulae represented by the filled circles were verified on at least one additional plate. Nevertheless the identities of many of these objects are open to question. In one case a Crossley photograph and a spectrogram by Gibson Reaves revealed that an apparent extragalactic object is, in fact, a small planetary resembling the Owl nebula. A second object highly plausible as a nebula proved to be stellar on another Crossley photograph by Reaves. It is probably a carbon star in which the strong blue-green region of the spectrum is sufficiently out of focus on the astrograph plates to give it the appearance of a nebula. The objects thus plotted individually should not be regarded definitely as extragalactic in nature, without further confirmation.

VII. DISTRIBUTION IN LATITUDE

The contour map shows clearly the well known correlation between the number of nebulae and the galactic latitude. From his counts Hubble derived the following expression for this relationship:

$$\log N_H = 2.115 - 0.15 \csc b,$$

where N_H is the number of nebulae and b is the galactic latitude.⁶ This equation is appropriate to a uniform layer of absorbing material lying symmetrically about the galactic equator and extending to infinity in all directions parallel to that plane. The irregularities in the distribution of galactic absorbing matter should produce departures from this simple formula, but it serves to delineate the obscuration approximately.

TABLE IV. VARIATION OF NUMBER OF NEBULAE WITH LATITUDE

Long. Interval	No. of Values of N	A	B	$\log N_H - \log N$	No. of Points
240°-260°	10	2.17	$-0.29 \pm .11$ (p.e.)	+0.10	6
260-280	16	1.78	$+0.05 \pm .07$	+0.05	14
280-300	20	2.12	$-0.29 \pm .07$	+0.07	41
300-320	24	2.25	$-0.43 \pm .03$	+0.16	18
320-340	23	2.42	$-0.51 \pm .03$	+0.13	18
340-360	23	2.46	$-0.55 \pm .03$	+0.15	15
0-20	5	2.46	$-0.54 \pm .16$	+0.52	3

The more complete data now available justify separate solutions, by 20° longitude intervals, of the equation

$$\log N = A - B \csc b,$$

where N represents the average of the corrected numbers of nebulae per square degree for each plate whose center lies within a given longitude interval. The constants, A and B , were determined by least-squares solutions for seven longi-

tude intervals in Area III. Values of N corresponding to $b < +25^\circ$ and a few values of N in the more conspicuous clouds were omitted from the solution. The results are included in Table IV.

The first four columns are self explanatory. The fifth column contains the means of the difference between the logarithms of Hubble's counts⁶ corrected for quality, $\log N_H$, and $\log N$ as calculated from A and B . The sixth column lists the number of values of $\log N_H$ used in forming these means. It should be noted that the first three values of B are subject to considerable inaccuracy due to the small range of b , and also due to the sensitivity of B to a possible systematic error in the amount of the atmospheric extinction.

For each of the seven longitude intervals, $\log N$ was plotted as a function of $\csc b$ (Figures 3 to 9). The straight line corresponding to the constants A and B is drawn for each figure. The points used in the solution are indicated by circles. Those that correspond to positions in large clouds of nebulae are represented by dots, and Hubble's values are shown by crosses. One of Hubble's points that coincides with a large cloud is omitted.

It is evident that in Area III the constant B is much larger than that derived by Hubble in the more extensive area covered by his survey. Since Area III includes part of the galactic bulge where the strong absorption persists to a considerable distance from the galactic equator, we would anticipate a larger absolute value of B than the 0.15 Hubble determined. However, the distribution of the points representing his observations in Area III suggests that a solution from them would yield a value of B even larger than ours.

An average value of B suitable for reducing the counts in Area III to a standard galactic absorption at the pole may be calculated from the data in Table IV. For this purpose it is recognized that the variation in B with longitude is for the most part real and does not result from accidental effects. Therefore the best average value is the unweighted mean. Since the corrections would ordinarily be used only in intermediate or higher latitudes, and since Area III does not include the longitude range $l = 0^\circ$ – 20° in these latitudes, we omit the last value of B in Table IV. The resulting mean is $\bar{B} = -0.34$. In an earlier paper by Neyman, Scott and Shane,⁷

Fig. 3 Long. = 240° to 260°

Fig. 4 Long. = 260° to 280°

Fig. 5 Long. = 280° to 300°

Fig. 6 Long. = 300° to 320°

Fig. 7 Long. = 320° to 340°

Fig. 8 Long. = 340° to 360°

Fig. 9 Long. = 0° to 20°

Figures 3–9. Relation between $\log \bar{N}$ and $\csc b$ for seven different ranges of galactic longitude.

the adopted value of $\bar{B}$ was -0.37 , derived by including the last entry in the table.

VIII. LIMITING MAGNITUDE OF THE COUNTS

The limiting magnitude of our counts may be derived from the values of $\log N_H - \log N$ for each of the longitude intervals, listed in the fifth column of Table III. The mean of these quantities, weighted according to the number of Hubble regions, is $+0.13$. However, for comparison with our counts, $\log N_H$ must be reduced to the area unit of one square degree, and his coma factor must also be applied. When this combined correction of $+0.70$ is included, we find that the logarithm of the ratio of Hubble's counts for limiting magnitude 20.0 to our counts is $+0.83$. If a uniform average density of nebulae in depth is assumed, and if the effect of red shift is neglected, the logarithm of the number of nebulae counted should increase by 0.6 per unit of limiting magnitude. Our limiting magnitude would therefore be 1.4 mag. brighter than Hubble's, or 18.6 mag.

It is more probable that the rate of increase in the log number of nebulae should correspond to Hubble's empirical value 0.501.¹ This value yields a difference in limiting magnitude of 1.64 mag. Thus we suggest for the counts published here an approximate limiting magnitude of 18.4 mag. based on Hubble's scale. Because of uncertainties in the stellar and nebular magnitude scales near the faint end, a substantial revision of this value may be necessary at some future time.

It should again be emphasized that the assignment of a limiting magnitude to the counts does not imply that all types of nebulae are counted to this magnitude. Some nebulae can no doubt be detected beyond the stated limit while others that are somewhat brighter than the limit escape detection. The value 18.4 mag. is merely a general average for all types of nebulae.

IX. IRREGULAR GALACTIC ABSORPTION

The contour map, Figure 2, strongly suggests irregularities in the galactic absorption. Two areas markedly deficient in nebulae occur at $l = 312^\circ$, $b = +34^\circ$ and at $l = 333^\circ$, $b = +35^\circ$. These regions of deficiency probably are due to galactic absorbing clouds. Other somewhat less conspicuous regions with abnormally small numbers of nebulae are readily noted, especially in low latitudes. In several of these regions low star densities indicate that at least some of the ab-

sorbing clouds are fairly close to the sun. The behavior of the long continuous contour showing 60 nebulae per square degree is particularly striking. It seems to outline a northward extension of the area of apparent absorption between longitudes 310° and 350° , south of latitude $+40^\circ$. The extension contains several isolated deficient regions, and it reaches nearly to latitude $+70^\circ$.

In determining the true nebular distribution, it is important to know whether absorbing clouds can be observed in high latitudes. Table V con-

TABLE V. DEFICIENT REGIONS

Gal. Long.	Gal. Lat.	3 Smallest Counts		
280°	+83°	20	24	28
281	+78	28	32	34
296	+65	28	32	33
259	+62	23	26	33
330	+62	28	28	30

tains the positions of five deficient regions north of latitude $+60^\circ$ for which the nebular count falls below 40 per square degree. In this connection it should be recalled that the smoothing process applied in constructing the contour map tends to suppress the extremes and therefore the deficiencies are actually greater than are indicated by the map. The third column of Table V gives the three smallest nebular counts in each of the regions listed. Because of accidental errors it would over-emphasize the deficiencies to tabulate merely the smallest count, but the mean of two or three should give a fair idea of the minimum number of nebulae per square degree. If these areas of deficiency do represent galactic absorbing clouds, there are probably other less conspicuous clouds not so readily noted on the contour map. There are three obvious methods of testing the hypothesis that such clouds occur in high latitudes.

First, if the hypothesis is correct, nebular deficiencies in any obscured area should tend to persist when the counts are made over a wide range of limiting magnitudes. Hubble's counts are not well adapted for use in conjunction with ours in making this test, because his plates are distributed in a regular pattern over the sky and only rarely fall in strongly deficient areas. Furthermore his actual counts extend to limiting magnitude 20 only at the center of his better 100-inch reflector plates. Before the coma factor is applied, Hubble's counts average only about one magnitude fainter than ours. Thus irregularities in our results should be reflected to a considerable degree in Hubble's counts. Table VI contains the correlation coefficients for a comparison of the $\log N_H$ and $\log N$ by zones of

galactic latitude. A definite positive correlation obviously exists but the meager data do not admit of any general conclusions as to the presence of irregular absorption in high latitudes. A survey of nebulae to about 15.5 magnitude has recently been undertaken at the Lick Observatory, and at a later time it is hoped to count nebulae on plates in selected regions photographed with the 120-inch reflector. A comparison of counts to the three limiting magnitudes, 15.5, 18.4 and 21 should provide a fairly definitive test of the hypothesis of absorbing clouds in high latitudes.

TABLE VI. CORRELATION WITH HUBBLE'S COUNTS

Latitude	No. of Comparisons	Correlation Coefficient
+80° to +65°	26	+0.46
+60 to +50	32	+0.47
+45 to +40	25	+0.60
+35°	7	+0.16
+30	6	-0.08
+25	6	+0.48

A second test consists of comparing star counts with nebular counts. Any definite, positive correlation that may be found to exist would be evidence of absorption.

Finally, a possible test for absorbing clouds could be based on the colors of nebulae in the deficient areas. A systematic reddening would be strong evidence of absorption. Unfortunately the dispersion of colors among the nebulae is so great that a large number of measures of faint objects would be required. There is considerable doubt if the labor of such a program would be justified by the results.

A number of other methods of uncertain promise in this connection could be suggested, such as a search for the 21 cm radiation of neutral hydrogen in the suspected regions, the strengths of interstellar lines, and measures of the surface brightnesses of nebulae as seen through the suspected absorbing clouds. Among all the methods suggested, however, the first two, based on nebular and star counts respectively, seem to offer the best possibilities.

It is probable that interstellar clouds exist in high latitudes, and their location and measurement, or at least the determination of their statistical properties, is of great importance in a study of the true distribution of the nebulae. The investigations by Neyman, Scott and Shane are based on the simplifying assumption of no irregular absorption in high latitudes.⁷ Ambartsumian, on the other hand, derived statistical

properties of the interstellar medium from Hubble's nebular counts on the assumption that the irregularities are due to galactic absorption.⁸ The actual situation may lie somewhere between these extremes.

X. SOME STATISTICAL PROPERTIES OF THE NEBULAR DISTRIBUTION

The appearance of the contour map, Figure 2, suggests that the nebulae are not distributed at random but tend to congregate in certain areas. So many aggregations stand out prominently that one is tempted to speculate that clustering may be a predominant characteristic of nebular distribution. In considering this possibility we note that nearby clusters are relatively few in number and their members are so widely separated on the sky that they are lost among the far greater number of distant nebulae. The Virgo cluster of bright nebulae is included on the contour map, but it is quite unrecognizable because of its small number of nebulae per square degree. This cluster becomes apparent only when one takes account of apparent magnitudes. Distant clusters, on the other hand, are very numerous and therefore closely spaced on the sky, but only their few brightest members may be visible on our plates. While these nebulae contribute materially to the total counts, their distribution, when studied by square degrees, should to some extent simulate a random distribution. There is in any survey, however, an intermediate range of distance most favorable for the detection of clusters by means of counts. Thus the aggregations so prominent on the map probably are in this range, while a considerable fraction of the structureless background may come from very distant clusters.

A test of the hypothesis that all nebulae belong to clusters was made by Neyman, Scott and Shane.⁷ For this purpose the counts in the less obscured region of Area III were analyzed. The analysis depended on certain reasonable assumptions regarding the structure of clusters. The investigation showed that the main statistical properties of the distribution could be represented by the hypothesis of complete clustering. On the other hand, it is quite possible that a different model that includes an appreciable number of random nebulae could be found to represent the observations equally well.

If the nebulae are individually distributed at random we should find (1) that the numbers in neighboring square degrees are uncorrelated, and (2) that they have a Poisson distribution. Neither

of these properties is possessed by the observed distribution.

(1) Serial quasi-correlations for the counts by square degrees corresponding to the west half of the contour map, Figure 2, were calculated under the direction of Scott in connection with the paper mentioned above. After correction for observational errors and for the effects of general galactic obscuration, it was found that counts in neighboring square degrees are correlated out to a distance of four to five degrees. Since the data are fully given in the reference they are not included here. These correlations in themselves strongly suggest that some kind of clustering is a prominent feature of nebular distribution.

(2) On the basis of his counts, Hubble showed that the logarithm of the number of nebulae per counted area closely approximates a normal frequency curve with a mean $\log N = 1.925$ and a dispersion, $\sigma = 0.18$.⁶ Mayall's counts of nebulae on plates taken with the Crossley reflector likewise give an approximately normal distribution in the logarithm, with $\log \bar{N} = 1.785$ and $\sigma = 0.22$.⁹ Bok pointed out that the σ derived by Hubble is so greatly in excess of the dispersion to be expected from a random distribution that a strong degree of clustering among the nebulae is indicated.¹⁰ Hubble also suggested a small-scale clustering to explain an apparent observed decrease in σ with increasing average numbers of nebulae in the counted areas.¹

Table VII contains the results of fitting our counts as well as certain counts by Hubble and Mayall to a normal distribution curve in $\log N$. The first three columns are self-explanatory. The fourth and fifth contain, respectively, the average actual numbers of nebulae counted per standard survey area and the mean of the logarithms of their corrected values. The sixth column gives the observed dispersion. In the seventh column σ_c is the dispersion corrected for errors of observation, based on probable errors in $\log N$ for Hubble, Mayall, and Shane and Wirtanen of

0.04, 0.04 and 0.054, respectively. The eighth column, σ_r , gives the dispersion in $\log N$ on the assumption of a random distribution. The ratios in the ninth column may be regarded as a measure of the departure from randomness. In view of the contagion in distribution, these numbers should show dependence on the average size of the samples counted in each row, but the range in sample size is not great enough to make the dependence obvious. The last column, P , gives the probability that if the true distribution in $\log N$ were normal, the χ^2 test would indicate a poorer fit than was actually found.

In Table VII the Hubble counts and those by Shane and Wirtanen north of latitude $+50^\circ$, all have values of P that strongly indicate a normal distribution in $\log N$. The Mayall counts in 71 areas are influenced by three plates very deficient in nebulae. If these plates were excluded, a normal distribution would represent the data reasonably well. The Shane and Wirtanen counts between latitudes $+40^\circ$ and $+50^\circ$ are greatly affected by the three large clouds in this region. But even if the areas of these clouds are omitted, the distribution has a strong skewness. The authors' counts between latitudes $+30^\circ$ and $+40^\circ$ are affected by local areas of galactic absorption and yield an excess of small values for $\log N$. When 1/30 of the largest and smallest counts were excluded, however, and the results were fitted to a partial normal curve in which the extremes were omitted, a good fit was obtained. The conclusion one may draw from this material is that, except where the counts are disturbed by unusual conditions, $\log N$ is represented very satisfactorily by a normal distribution function.

The values of σ_c/σ_r range from 2.2 to 2.4 except in regions strongly affected by large clouds of nebulae or by irregular galactic absorption. This large departure from unity strengthens the conclusion that nebulae tend to occur in clusters.

TABLE VII. COMPARISON OF OBSERVED AND RANDOM DISPERSIONS IN $\log N$

Authority	Lat.	No. of Areas	$\bar{N}_c$	$\overline{\log N}$	σ	σ_c	σ_r	$\frac{\sigma_c}{\sigma_r}$	P
Hubble*	45°	148	50.3	1.898	0.148	0.136	0.062	2.2	0.34
Mayall†	45	71	38.1	1.756	.230	.222	.074	3.0	<.01
S and W	>70	431	63.9	1.806	.154	.132	.054	2.4	.59
S and W	$60^\circ-70^\circ$	508	68.3	1.837	.148	.125	.053	2.4	.27
S and W	$50-60$	656	58.9	1.770	.156	.135	.057	2.4	.69
S and W	$40-50$	827	55.9	1.725	.208	.193	.060	3.2	<.01
S and W	$30-40$	671	32.1	1.484	.212	.197	.081	2.4	<.01
S and W	$30-40^{**}$	649	32.1	1.490	0.197	0.182	0.081	2.3	0.54

* 1 hr. exposures with the 100-inch telescope.

† 1 hr. exposures with the 36-inch Crossley.

** The largest and smallest counts contributing 1/30 to the total were omitted.

XI. THE CLUSTER DENSITY FUNCTION

There appear to be two extreme structural types among the populous clusters, exemplified by the Virgo and the Coma clusters. The Virgo type is characterized by the absence of a strong central condensation and by lack of symmetry. Such clusters cannot readily be recognized at great distances where they become confused with the general background of nebulae, and therefore not many are known. They may be regarded as "open" clusters of nebulae. The Coma-type cluster is characterized by a strong central condensation and a tendency toward spherical symmetry. Such clusters can be recognized at great distances and are found in large numbers on the photographs. There may well be intermediate types, but at present our knowledge is too fragmentary to discuss their structure.

A considerable number of Coma-type clusters appear on the photographs of Area III. It is therefore worth while to investigate in a very preliminary fashion the manner in which the surface density in such clusters diminishes with distance from the center. Six of the clusters are suitable for such a study. All six are rather small or are somewhat disturbed by proximity to the edges of the plates, or to other clusters, and they therefore could not be investigated individually. The data were combined to form an average cluster whose density gradient could be determined.

The six clusters: For each cluster the center was located by inspection and the central count was recorded. The mean of the counts for the squares adjoining its four sides gave the value at 10' from the center. This process was continued outward by grouping conveniently increasing numbers of squares located within a sufficiently small range of distance until there was no longer an appreciable decrease in numbers of nebulae. Areas that were obviously disturbed by nearby clusters or groups of nebulae were avoided. A provisionally estimated value of the background was subtracted from the counts for each cluster, the resulting values were plotted against distance from the center, and a smooth curve was drawn to represent the points as well as possible. The curves for all six clusters were characterized by an initial rapid decrease in numbers of nebulae, followed by a very slow approach to zero. To reduce the observations to a common basis, abscissa and ordinate correction factors were derived for each cluster. The abscissa factor was determined by finding the abscissa at which the

TABLE VIII. SIX COMA-TYPE CLUSTERS

α 1950	δ 1950	Abscissa Factor	Ordinate Factor
12 ^h 16 ^m 3	+ 5° 35'	0.84	1.30
12 16.9	-13 05	1.06	1.37
12 39.0	- 4 35	0.90	1.40
14 24.5	+16 55	1.06	0.82
14 50.6	+16 55	1.06	0.64
14 52.6	+18 55	1.17	0.94

ordinate fell to one-third of its maximum value as read from the curves. The scale of abscissae was then multiplied by a number to make this "one-third point" the same for all clusters. A single ordinate factor was determined for each cluster to bring all six curves into the best agreement. When the individual observations corrected by these factors were plotted on a single chart, a large scatter was evident. The points were then grouped into eleven means or normal points on which the further discussion is based. The positions of the six clusters together with their coordinate factors are listed in Table VIII.

TABLE IX. CLUSTER DENSITY FUNCTION

Six Clusters				
r	n_r obs	O-C	r	n_r obs
0.00	14.3*	+1.3*	10.8	0.6
1.09	4.8	-0.2	12.3	0.4
1.70	3.3	+0.1	12.9	0.4
2.35	2.16	-0.08		
2.90	2.13	+0.40	Coma Cluster	
3.32	1.33	-0.16	Plate 303	Plate 1613
3.87	1.44	+0.22	r	n_r obs
4.47	1.02	0.00	n_r obs	O-C
5.28	0.83	+0.03	0.0	30.0*
6.52	0.61	+0.01	1.0	20.2
7.97	0.41	-0.03	1.4	11.5

* For $r = 0$ the observed values are the numbers of nebulae in a 10' square corrected for background. The computed values are the numbers within a circle of 100 square minutes area.

The average number of background nebulae subtracted from the counts was 1.5 nebulae per 10' square. This value is certainly too large since it is based on the distance at which the counts were terminated. With the evident slow decrease in numbers of nebulae outward from the center a greater distance should be used to establish the true background density. For each cluster several areas, two or more degrees from the center, were located in which there seemed to be little or no effect of nebular aggregations. The background densities derived from these areas gave a mean value of 1.1 nebulae per 10' square. Each of the eleven normal points was accordingly increased by 0.4. The first and second columns of Table IX give, respectively, distances, r , in units of 10' from the center of the average cluster, and the corresponding corrected surface densities.

Two plates of the Coma cluster (α 1950 = $12^h 57^m 5$; δ 1950 = $+28^\circ 20'$), which lies just off the northern edge of Area III, were investigated separately.

The Coma Cluster, Plate 303. This plate, a two-hour exposure centered on the cluster, was taken without the grating. Figure 10 represents the nebular density distribution by contours whose interval is four nebulae per ten minute square. The contour for two nebulae per ten minute square is shown by the broken line. In drawing the contours the counts were averaged by fours in the usual manner. However, the numbers on the chart give the actual counts. It

is apparent that there is a subsidiary concentration of nebulae southwest of the cluster center. This grouping may be a secondary feature of the cluster or it may represent an independent aggregation. The area included in the rectangle outlined by the broken lines was therefore not used in discussing the density function. With this omission the cluster approximates circular symmetry.

The position of the largest count, 31, was adopted as the center of the cluster. The true center probably lies somewhere between counts 31 and 22, but this centering error should appreciably effect only the central count. At 130' from the center the average number of nebulae per ten minute square reached 1.4 and was no longer decreasing noticeably. This distance seemed to correspond to the average distances at which the counts on the six clusters were terminated. Consequently, as with the 6 clusters, the terminal value was decreased by 0.4 to give a background count of 1.0. The surface density corrected for this background is given in the second column of the lower part of Table IX.

The Coma Cluster, Plate 1613. This plate was taken on the regular program and includes the cluster centered 105' south and 35' west of the plate center. Figure 11, the contour representation for this plate, indicates a close similarity to the chart for Plate 303 but with a fainter limiting magnitude. If a Number 6 contour were drawn on Plate 303, it would correspond rather closely to the Number 8 contour on Plate 1613. The

Fig.10. Plate 303

Fig.11. Plate 1613

Figures 10 and 11. Contour maps of the Coma cluster of nebulae, based on smoothed counts by 10' squares.

latter plate has a uniformly higher density of nebulae, with 2.2 or 2.3 nebulae per ten minute square at 130' from the cluster center. Since the cluster was considerably south and west of the plate center, it was possible to find relatively undisturbed areas of background near the north edge of the plate. The average count in these areas was 1.6 nebulae per square degree. Correction for this background density was applied to the counts with the results tabulated in the fourth column of the lower part of Table IX.

Empirical formula of de Vaucouleurs. It has been shown by G. de Vaucouleurs that a formula equivalent to $\log n_r = a(r^1 + b)$ represents with remarkable fidelity the observed distribution of brightness in elliptical nebulae.¹¹ His value $b = -1$ corresponds to the adoption of a special unit of brightness in his applications. De Vaucouleurs¹² also applied the formula to nebular counts by Zwicky¹³ in three clusters of nebulae and obtained an excellent representation. The formula was applied to our observations with the results represented by the O-C columns of Table IX and the constants in Table X. The

TABLE X. CONSTANTS FOR DE VAUCOULEURS' FORMULA

	a	b	r_e	Neb. inside r_e
Six Clusters	-1.595 (-1.738)	-1.458 (-1.426)	19.01 (13.48)	405 (290)
Coma Cl., Plate 303	-1.855 (-1.938)	-1.677 (-1.652)	10.38 (8.71)	738 (642)
Coma Cl., Plate 1613	-1.745 (-1.807)	-1.759 (-1.738)	13.25 (11.54)	1153 (972)

quantities in Table X not enclosed in parentheses are based on the observational data in Table IX; those in parentheses are derived from n_r diminished throughout by 0.1. This change corresponds to raising the assumed background by 3.6 nebulae per square degree, an amount within the uncertainties of its determination. The column headed r_e gives the distance from the center of each cluster within which half the total number of nebulae should lie, according to the formula. The number within the distance r_e is given in the last column of the table. The total number of nebulae to $r = \infty$ is twice this value for each cluster. The constants in Table X were determined without using the observational data for $r = 0$. Clearly, the equation does not fit at the immediate center of the Coma cluster, but elsewhere the agreement is good.

The important point to be noted is that the density of nebulae in a Coma-type cluster, and

the brightness of an elliptical nebula, decrease outward in much the same manner.

XII. CLOUDS OR MULTIPLE CLUSTERS

In the list of twenty-five clusters of nebulae published by Shapley,¹⁴ he noted the occurrence of two double groups and one triple group. He suggested that these multiple groups were physically connected because of the proximity of the members both in direction and in distance as indicated by their distribution in apparent magnitude.

In Area III there occur three large multiple clusters or clouds of nebulae and several smaller ones. Contour maps of six of these clouds are illustrated in more detail in Figures 12 to 16 than in the main chart, Figure 2. The corrected counts by quarter instead of whole square degrees were smoothed by fours and then contours were drawn through the smoothed points. The contour interval is ten nebulae per square degree. It is apparent that each cloud consists of two or more comparable clusters with subsidiary condensations, except for the cloud at $\alpha = 14^h 25^m$, $\delta = +16^\circ 7'$. An examination of the unsmoothed counts for this cloud shows that the ridge extending to the northwest is produced by two secondary aggregations of nebulae whose identities were lost through the smoothing process.

Data for the six clouds are given below. All positions are for 1950. Distances are given on the scale proposed by Baade at the Rome I.A.U. meeting in September 1952.

1. Figure 12: $\alpha = 12^h 16^m$, $\delta = +4^\circ 8'$. In 14.8 square degrees 505 nebulae above a background of 80 nebulae per square degree. Two main centers of condensation at $\alpha = 12^h 15^m$, $\delta = +4^\circ 0'$; $\alpha = 12^h 16^m$, $\delta = +5^\circ 5'$.

2. Figure 13: $\alpha = 12^h 54^m$, $\delta = -15^\circ 2'$. In an area of 25 square degrees 1388 nebulae above a background of 80. Distance of the southernmost condensation based on magnitude distribution according to Shapley,¹⁴ 58×10^6 parsecs. Three major condensations at $\alpha = 12^h 51^m$, $\delta = -15^\circ 2'$; $\alpha = 12^h 55^m$, $\delta = -17^\circ 2'$; $\alpha = 12^h 55^m$, $\delta = -13^\circ 2'$. Also two minor condensations.

3. Figure 14: $\alpha = 14^h 25^m$, $\delta = +16^\circ 7'$. In 6.5 square degrees 214 nebulae above a background of 88. One major condensation at $\alpha = 14^h 25^m$, $\delta = +16^\circ 7'$. Two minor condensations at $\alpha = 14^h 20^m$, $\delta = +17^\circ 8'$; $\alpha = 14^h 16^m$, $\delta = +18^\circ 8'$.

4. Figure 14: $\alpha = 14^h 52^m$, $\delta = +17^\circ 9'$. In 8.2 square degrees 359 nebulae above a background

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Figures 12-16. Contour maps of clouds of nebulae, based on smoothed counts by 0.5° squares.

of 88. Two main condensations at $\alpha = 14^h 51^m$, $\delta = +17^\circ 0'$; $\alpha = 14^h 53^m$, $\delta = +18^\circ 8'$.

5. Figure 15: $\alpha = 15^h 12^m$, $\delta = +5^\circ 2'$. In 52 square degrees 2810 nebulae above a background of 68. Three major condensations at $\alpha = 15^h 09^m$, $\delta = +6^\circ 0'$; $\alpha = 15^h 11^m$, $\delta = +4^\circ 8'$; $\alpha = 15^h 17^m$, $\delta = +4^\circ 5'$. Three to five minor centers of con-

densation. Spectrograms of two nebulae at $\alpha = 15^h 20^m 4$, $\delta = +8^\circ 47'$ in a minor condensation, kindly obtained by Dr. Mayall to estimate the distance of the cloud, give red shifts $+10,500$ and $+10,400$ km/sec; with the corresponding distance 39×10^6 parsecs.

6. Figure 16: $\alpha = 16^h 02^m$, $\delta = +17^\circ 0'$. In 20.2

square degrees 1248 nebulae above a background of 60. Two major condensations at $\alpha = 16^{\text{h}} 03^{\text{m}}$, $\delta = +17^{\circ}8$; $\alpha = 16^{\text{h}} 01^{\text{m}}$, $\delta = +16^{\circ}2$. One or two minor condensations. Both major condensations listed by Shapley,¹⁴ who gives 46×10^6 parsecs for both clusters. Seven nebulae observed spectrographically by Humason, to whom we are indebted for communicating the observations in advance of publication, give a mean velocity of $+10,300$ km/sec, with the corresponding distance 39×10^6 parsecs.

Although no statistical tests have been applied, the number of multiple aggregations of nebulae noted thus far suggests that there is a strong tendency for clusters to occur in groups of two or more. Two clusters outside the boundaries of Area III have also been examined. The well known Coma cluster is single, as mentioned, except for a possible small subsidiary condensation about $0^{\circ}7$ southwest of the center. The Corona Borealis cluster appears to be the southern and most pronounced condensation of a large cloud of nebulae.

It is not improbable that when all the material has been analyzed, some of these preliminary conclusions may require modification. A great deal of supplementary information can be obtained by examining the detailed counts more closely and by repeating with different conditions of exposure some of the plates in critical areas. It is our hope to extend the work in this direction.

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