THE VELOCITY-DISTANCE RELATION FOR ISOLATED EXTRAGALACTIC NEBULAE

BY EDWIN HUBBLE AND MILTON L. HUMASON

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Read before the Academy, Monday, April 23, 1934

The velocity-distance relation was first established[1] for a few nebulae whose distances were derived from involved stars. With the aid of data from clusters whose relative distances were estimated from the mean apparent magnitudes of the many members of each cluster, the relation was confirmed in the form[2]

$$\log v = 0.2\, m + 0.51,$$

which, since

$$\log d = \frac{m - M + 5}{5},$$

leads to the linear relation

$$v = 10^{(0.2M - 0.49)} d,$$

where M is the mean absolute magnitude of cluster nebulae.

In both cases the isolated nebulae in which no stars were detected, i.e., nebulae for which total luminosity must serve as a criterion of distance, were used in general for confirming the order of the results rather than for their precise formulation. This procedure was employed because of the rather large effects resulting from the selection of isolated nebulae according to apparent magnitude, which the data were insufficient to evaluate. Mr. Humason has since accumulated velocities for 35 isolated nebulae, which, together with the 50 previously available, form a body of data adequate for the purpose.

The new data are listed in table 1, in which the magnitudes are taken from the convenient Harvard Survey of the brighter nebulae, with the exception of the 6 faintest, which represent estimates by one of the writers. The velocities, in km. per sec., are not corrected for solar motion. The data previously available may be found in the two former discussions of the velocity-distance relation.

Actually, 94 velocities are available, but 9 have been rejected, of which 7 belong to our own local group and give velocities that are mere reflections of the rotation of the galactic system (the two satellites of the galactic system, namely, the Magellanic Clouds, M 31 with its two satellites, M 33, and NGC 6822); one, IC 342, a large open spiral at latitude + 12° and obviously affected by local obscuration, may belong to the same category;

and finally NGC 404, $v = +40$ (corrected for solar motion), $m_{pg} = 12.0$, an exceptional case which would unduly influence the correlation under investigation. NGC 404 is not necessarily inconsistent, since permissible values of absolute magnitude and peculiar motion may be assigned which would account for the apparent discrepancy.

TABLE 1

RADIAL VELOCITIES OF ISOLATED NEBULAE

NGC	TYPE	m_{pg}	v	NGC	TYPE	m_{pg}	v
157	Sc	11.2	+1800	3377	E5	11.6	+ 650
628	Sc	11.2	600	3384	SBa	11.3	850
720	E5	11.7	1800	3412	SBa	11.6	950
722	Sb	12.0	2200	3414	SBb	12.2	1450
1084	Sc	11.2	1450	3486	Sc	11.4	1250
1087	Sc	11.2	1850	N_2	E	17.5*	19000
1332	Sa	11.4	1400	3726	Sc	11.7	1150
1400	E1	12.5	500	5253	Ir**	10.8	400
1407	E0	11.5	+2000	5846	E0	11.6	1700
IC 342	Sc	(14.0)*	− 25	5982	E3	12.7*	+2900
N_1	Sa	16.0*	+4600	6946	Sc	11.1	− 150
2403	Sc	10.2	125	7177	Sbc	12.1	+1300
2655	Sa	11.6	1350	7343	SBb	14.1*	1200
2768	E6	12.0	1400	7727	Sa	12.0	1800
2775	Sa	11.5	1100	7814	Sa	12.4	+1000
2787	SBa	12.1	700				
2903	Sc	10.3	350				
3147	Sc	11.9	2600				
3344	SBc	11.9	550				
3351	SBb	11.5	+ 700				

* Magnitudes estimated at Mount Wilson; that for IC 342 is very uncertain.

** Emission spectrum. Type uncertain since the possibility that the object is a planetary is not ruled out. The point is important because of the nova Z Centauri, which appeared in this nebula and attained a maximum many times the total luminosity of the nebula.

N_1 and N_2 are faint nebulae at R. A. = $4^h\,37\overset{m}{.}0$; Dec. = $+4°\,7'$ and R. A. = $10^h\,54\overset{m}{.}0$; Dec. = $+57°\,12'$ (1930), respectively.

N_2 is within the field of a very faint cluster found by Dr. Baade but is about 0.5 mag. brighter than the estimated upper limit of the cluster nebulae. The spectrum was observed on the slight chance that the nebula might be an outstanding member of the cluster. The red-shift actually observed is about half the value predicted for the cluster and hence the nebula is very probably a normal field nebula.

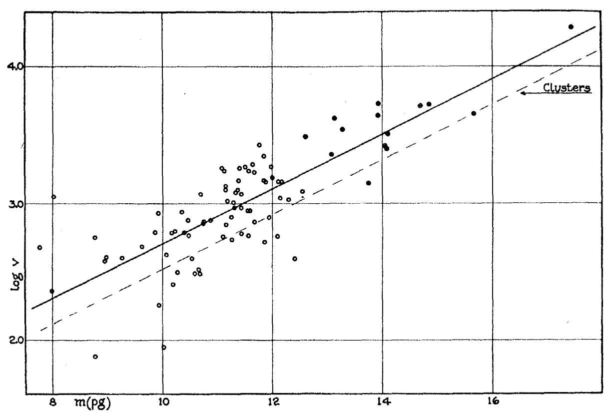
Figure 1 exhibits the correlation between m (from the Harvard Survey or from Mount Wilson estimates), corrected for local obscuration,[3] and log v, corrected for solar motion,[1] for the 85 remaining nebulae. A linear correlation is evident, and a least-squares solution, with the data grouped according to log v, leads to the relation

$$\log v = (0.203 \pm 0.010)m + 0.67.$$

When the precisely linear coefficient of m, namely, 0.2, is adopted, the relation, together with that derived from the clusters, is

Isolated Neb.	$\log v = 0.2m + 0.71$
Clusters	$\log v = 0.2m + 0.51$
	0.20
$\sigma = 0.862$	$0.2 \times 1.38\sigma^2 = 0.20$

The significance of σ, the dispersion, will be discussed later. The relation for isolated nebulae parallels that for the clusters but is displaced just one



Velocity-Distance Relation for Isolated Nebulae
FIGURE 1

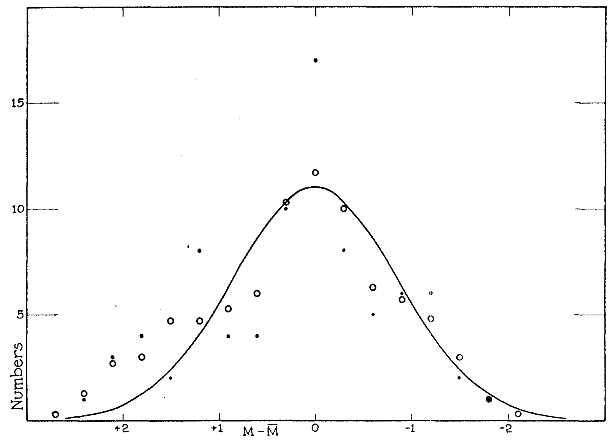
magnitude toward the brighter side. This displacement represents the effect of selection.

The luminosity function of nebulae (the frequency distribution of absolute magnitudes for the nebulae in a given volume of space) approximates a normal error-curve with a maximum at M_0 and with a dispersion rather uncertainly estimated at less than a magnitude. The density function, at least on the grand scale, is approximately constant. These conditions represent the classical example of the simplest case in statistical studies of stellar distribution, which has been fully discussed by Malmquist.[4] The point of immediate interest is the frequency distribution of absolute magnitudes among nebulae of a given apparent magnitude. This function is found to be another normal error-curve, with the same dispersion as the luminosity function but with the maximum, $\overline{M}$, displaced toward the brighter side by the amount

$$M_0 - \overline{M} = 1.38\sigma^2,$$

where the coefficient is $0.6 \log_e 10$. In other words, when nebulae are selected on the basis of apparent magnitude, the absolute magnitudes are too bright by the systematic term $1.38\sigma^2$.

Since the effect of selection applies to the isolated nebulae and not to the



Frequency Distribution of Residuals in Velocity-Distance Relation

FIGURE 2

The smooth curve is a normal error-curve with a dispersion of 0.86. Numbers of nebulae in intervals of 0.3 mag. are represented by dots; overlapping means for three successive intervals, by open circles. Two nebulae fall outside the limits of the diagram: On the brighter side, NGC 4594, whose magnitude is very uncertain; on the fainter side, NGC 6946, whose observed velocity is small compared with the average peculiar motion of nebulae.

clusters, the observed displacement in the velocity-distance relation is in the direction and of the order to be expected. The displacement represents a dispersion

$$\sigma = \sqrt{\frac{0.20}{0.2 \times 1.38}} = 0.86,$$

which agrees with the dispersion derived from the residuals themselves, namely, 0.862. The frequency distribution of the residuals is exhibited in figure 2. The precise agreement is a coincidence, since the residuals include all errors and peculiar motions and hence lead to a value larger than the true dispersion, while the data for the clusters when slightly revised for galactic obscuration, etc., give a slightly smaller displacement. These second-order corrections, together with the effect of magnitude errors, will be more fully discussed in a *Contribution* from the Mount Wilson Observatory.

Meanwhile it is evident that, within the small uncertainties, the isolated nebulae exhibit the same relation as the cluster nebulae and hence that their luminosity functions are closely similar. The important quantity M_0 is most reliably derived from the Virgo Cluster whose distance is indicated by stars involved in the later-type spirals. Reëxamination of data available at present suggests no significant revision of the earlier estimate,[2] -13.8, although the round number -14 might be used with about equal justification pending the detailed analysis of the Virgo Cluster.

The statistical correction, $M_0 - \overline{M}$, affects investigations of distribution by counts of nebulae and reduces the previously[3] estimated values of the density of matter in the observable region by a factor of the order of three. At great distances the correction diminishes as the red-shifts increase, and beyond about the nineteenth magnitude the variation cannot be ignored.

[1] *Mount Wilson Comm.*, No. 105; *Proc. Nat. Acad. Sci.*, **15**, 168–173 (1929).

[2] *Mount Wilson Contr.*, No. 427; *Astrophys. J.*, **74**, 43–80 (1931).

[3] Magnitudes are corrected for galactic latitude by the cosecant law $\Delta m = 0.15$ (cosec $\beta - 1$). *Mt. Wilson Contr.*, No. 485; *Astrophys. J.*, **79**, 8–76 (1934). The corrections are required by the fact that most of the faint nebulae are in very low latitudes.

[4] K. G. Malmquist, "On Some Relations in Stellar Statistics," *Arkiv för Matematik. Astronomi och Fysik*, Stockholm, **16**, No. 23 (1921).

HEAT INDUCED MUTATIONS IN DROSOPHILA

BY H. H. PLOUGH AND P. T. IVES

DEPARTMENT OF BIOLOGY, AMHERST COLLEGE

Communicated March 28, 1934

Although irradiation by x-rays remains the only reliable method for inducing mutations artificially, the discovery by Goldschmidt[1] that gene mutations were induced by exposing larvae of *Drosophila* for 24 hours to a sub-lethal temperature of 36° has stimulated interest in the problem of the origin of mutations in nature. The result had been suggested by the previous work of Muller and Altenberg[2] and of Muller,[3] but the results of Goldschmidt and more recently of his co-worker Jollos[4] constitute an important contribution to genetics which is the more interesting since there have been so many previous breeding experiments with *Drosophila* at