PRECISE DETERMINATION OF THE DISTANCES OF GALAXIES

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ABSTRACT

The Space Telescope shall be useful to check the local extragalactic distance scale to within 10-15 percent. It opens up the opportunity to determine relative distances of cosmic standard candles, viz. brightest M-supergiants and SNe I in E galaxies. The M-supergiants shall map the velocity field out to $v_o \approx 3000$ km s^{-1} thus providing (1) a firm basis for the determination of H_o (global) from local distances; (2) the possibility to derive precise distances of all nearby field galaxies from their recession velocities; and (3) in combination with the density profile of the Virgo complex an accurate value of the density parameter Ω/Ω_{crit}. Photometry of the SNe I out to z = 0.5 shall lead to a direct determination of q_o via the Hubble diagram, and the form of their light curves offers a fundamental test on the nature of redshifts. The independent determination of Ω/Ω_{crit} and q_o shall give an estimate of the smoothly distributed, invisible matter in the universe and test the assumption $\Lambda = 0$.

1. INTRODUCTION

Except for the nearest galaxies, where the brightest stars (Cepheids, early and M-type supergiants, RR Lyr stars, etc.) can be resolved, there exists no single field spiral galaxy whose distance would be better known than within ~25 percent; and for early-type galaxies (E, S0, Sa) there is actually no way to determine their absolute distances.

It is therefore evident that the best distances to an

*Operated jointly by the Carnegie Institution of Washington and the California Institute of Technology

https://doi.org/10.1017/S0252921100111030 Published online by Cambridge University Press

unlimited number of individual galaxies (and aggregates of galaxies) shall come from their (mean) recession velocities v_o, corrected for all possible deviations from an ideal Hubble flow, in combination with the global value of H_o. The deviations from an ideal Hubble flow can be mapped using *relative* distances only, and once this is achieved, the value of H_o can be determined with much better accuracy than the distance to any individual galaxy, because H_o is found from the *mean* of the ratios r/v_o (corrected) for all galaxies for which estimates of the distance r are available.

After a short discussion of the status quo of H_o (Section 2), the reasons are exposed why H_o can presently not be obtained to an accuracy of better than 10-15 percent, and it is shown that several of these problems shall not be solved by the Space Telescope (Section 3), at least not with a direct attack. In Section 4 the possibilities of the Space Telescope are considered of checking the extragalactic distance scale within the before-mentioned accuracy out to ~10 Mpc using RR Lyr stars and especially Cepheids. The highly promising potentials of the Space Telescope to map the local velocity field by means of the brightest M-supergiants are developed in Section 5. Finally, it is shown in Section 6 that the search for and photometry of supernovae of Type I out to redshifts of z = 0.5 is feasible with the Space Telescope, and that the Hubble diagram of these objects offers a unique chance for the determination of q_o.

2. H_o FROM GROUND-BASED OBSERVATIONS

Probably the most objective picture of the present knowledge of H_o comes from a comparison of the two most divergent views presently in the literature. Of these distance scales the one is proposed by Sandage and Tammann (1976 and references therein; hereafter referred to as the ST scale), the other one by de Vaucouleurs (1979 and references therein, hereafter referred to as the V scale).

As can be seen from Table 1, the distances of the V scale are on the average 18 percent smaller. There is a tendency of the differences to increase with distance: from 16 percent in the Local Group to 26 percent at the Virgo cluster. (Surprisingly the agreement of the mean distance of the M81 group --irrespective if this group is considered a physical entity or not--is almost perfect.)

The overall agreement is not too bad, indeed, and there is reason to believe that the discrepancies can be narrowed

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Table 1: Comparison of ST and V Scales

Object	(m-M)°(ST)	(m-M)°(V)	⟨ST - V⟩
Within Local Group (n = 6)	---	---	$0^m_.32$
M81 Group (n = 6)	$27^m_.56$	$27^m_.54$*	$0^m_.02$
M101 Group	$29^m_.30$	$28^m_.70$*	$0^m_.60$
Virgo Cluster	$31^m_.50$	$31^m_.00$*	$0^m_.50$

*The published values are still based on a CSC-law of galactic absorption as derived from galaxy counts. Since it is now known that galaxy counts cannot yield the absorption at the poles (Noonan 1971; Heiles 1976) and that the galactic polar caps are essentially absorption-free (Sandage 1973, 1975, 1976a; Sandage and Visvanathan 1978; Burstein and Heiles, 1978), all moduli are reduced here to zero-absorption at the poles.

down in the near future. For instance, a great leap forward has recently been made with the Cepheids in LMC by Martin et al. (1979); they included infrared magnitudes of galactic and LMC Cepheids to control metallicity effects, and they based their zero-point not only on the Hyades modulus but also on purely physically derived distances from the Baade-Wesselink method. The resulting LMC modulus is $0^m_.38$ *larger* than that of the V scale, and since LMC is a fundamental local calibrator, the change shall perpetuate through the whole V scale with considerable weight. In addition, at the distance of M101 the V scale cannot explain why Cepheids have so far escaped detection, and the brightest blue stars in M101--now spectroscopically confirmed by Humphreys (1979a)--would be fainter than the brightest stars in the solar neighborhood, which seems unacceptable. Finally, there is a strong suspicion that the V scale suffers from a Malmquist-type bias at the distance of M101, which increases with increasing distance--exactly in the sense in which the Malmquist effect is known to act.

To illustrate this point it must be stated that the V scale implies an increase of H_o beyond the Virgo cluster:

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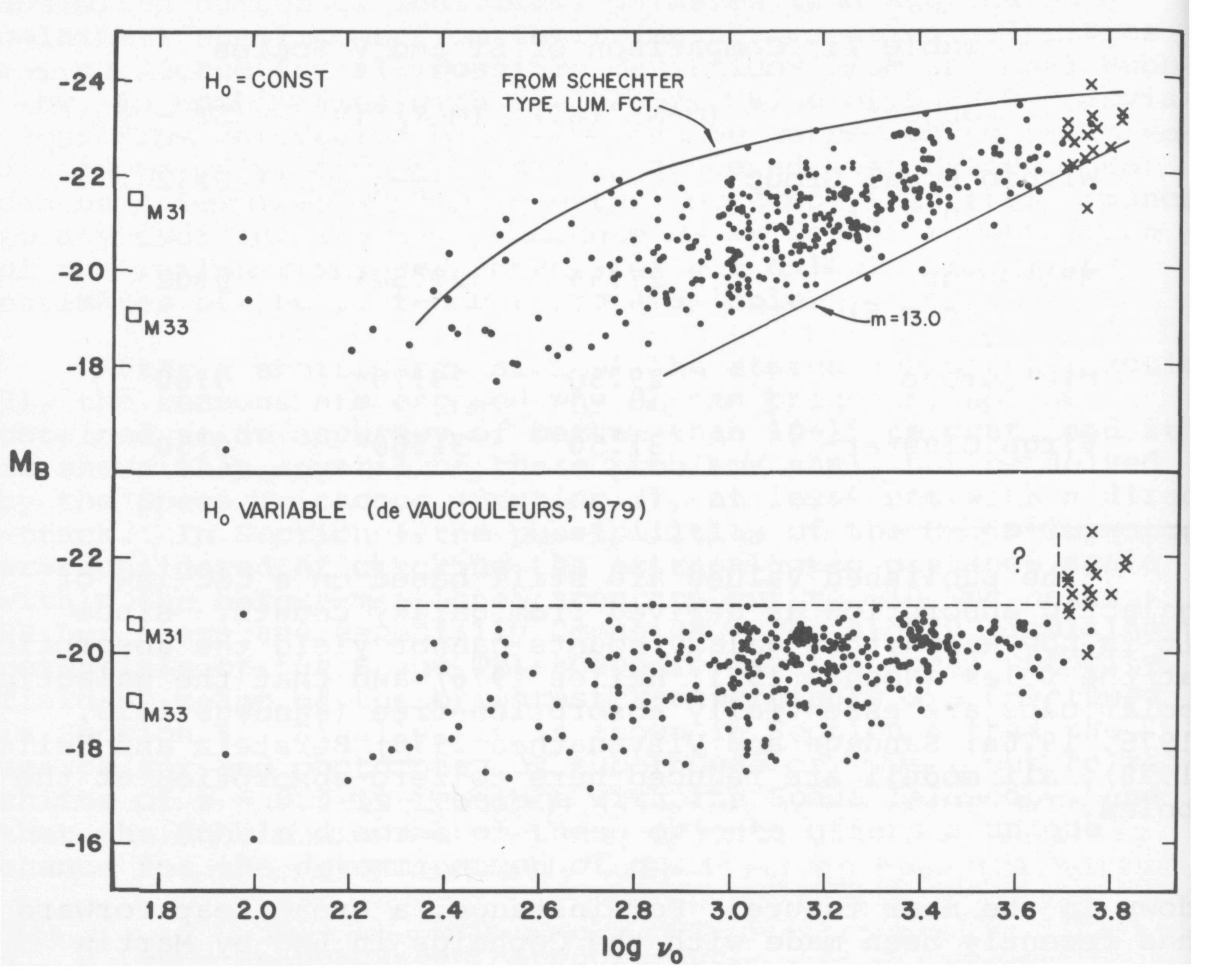

Fig. 1. Upper panel: The dependence of absolute magnitude M_B on log v_O for 327 spiral galaxies from de Vaucouleurs' (1979) list. The values M_B are derived assuming a uniform value of H_O (here H_O = 50). The point distribution is well bound by an upper envelope calculated from a Schechter-type luminosity function. The Shapley-Ames spiral galaxies with $v_O > 5000$ km s^{-1} are also plotted (crosses); they fit smoothly to the upper boundary. — Lower panel: The same galaxies are plotted, but this time using de Vaucouleurs' (1979) individual distances and H_O = 90 beyond v_O = 5000 km s^{-1}. The flat upper boundary and the jump in M_B at $v_O \approx 5000$ km s^{-1} requires a strange luminosity function with a pronounced discontinuity at $M_B = -21^m$.

while it requires $H_O \approx 70$ [km s^{-1} Mpc^{-1}] at Virgo, it suggests $H_O \approx 82$ at $v_O \approx 3000$ km s^{-1} (these values hold after the above-mentioned absorption correction). It can easily be

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shown that this apparently modest change of H_o(local)/H_o(global) = 0.85 already leads to unacceptable consequences. The V scale out to larger distances is defined by 327 spiral galaxies, which are drawn from an essentially *magnitude-limited* sample of galaxies and which are proclaimed to be somewhat biased toward *high-luminosity* galaxies; for these galaxies distances were determined by at least four different equations (de Vaucouleurs 1979; Table 1). Their implied absolute magnitudes are plotted against log v_o in Figure 1 (lower panel). The striking result is that the absolute magnitudes have a sharp upper bound at $M_B = -21^m$. This can only be explained if one assumes that spiral galaxies have a well-defined upper luminosity cutoff, because even the very large volumes surveyed at large v_o do not provide any bright galaxies. However, if one uses the global value of H_o of the V scale, i.e., $H_o = 90$ (before galactic absorption correction in order to achieve consistency in Fig. 1), to determine the absolute magnitudes of all additional Shapley-Ames galaxies with $v_o \geq$ 5000 km s^{-1}, one finds that most of them are much brighter than -21^m! This result is equivalent to a very pronounced discontinuity of the galaxian luminosity function.

It was recently shown that the upper envelope in an M versus log v_o plot for an apparent-magnitude-limited sample of galaxies can be used to determine the galaxian luminosity function (Sandage et al. 1979). Instead of deriving the highly strange luminosity function from the lower panel of Figure 1, I have replotted the same 327 galaxies in the upper panel of Figure 1, this time using a *constant* value of H_o (here $H_o = 50$). In addition, an upper envelope was calculated from a Schechter luminosity function, using appropriate parameters for spiral galaxies (Tammann et al. 1979) and an appropriate normalization (Yahil et al. 1980). The good agreement of the *form* of the calculated envelope with the point distribution is strong support for the assumption that spiral galaxies have a normal Schechter-type luminosity function, if only one uses a correct distance scale, i.e., a uniform expansion field. That spiral galaxies conform indeed with the Schechter function is independently evidenced by the spiral members of the Virgo cluster (Tammann and Kraan 1972). (Note, the form of the luminosity function does not depend on the adopted value of H_o, only on its constancy. Note also that the apparent excess of nearby bright galaxies in the upper panel of Fig. 1 is expected because of the local density anomaly due to the Local Supergalaxy.)

There are other observations which restrict the size of any peculiar streaming motions of galaxies, and hence of any variation of H_o. The most stringent limits on such motions are set by three *independent* methods, using relative distance indicators only:

(1) A comparison of field galaxies with known redshifts and Virgo cluster galaxies provides a predicted Virgo cluster velocity. Using surface photometry (Kormendy 1977), the color luminosity relation of E and S0 galaxies (Visvanathan and Sandage 1977), and the apparent luminosity function of Shapley-Ames galaxies (Tammann et al. 1979a) predicts a mean Virgo cluster velocity of 1098 ± 60 km s^{-1} (Tammann et al. 1979b).

(2) On the reasonable assumption that the mean velocity of the Coma cluster of 6890 km s^{-1} reflects the cosmic expansion velocity to better than 90 percent, one can predict the Virgo velocity from the distance modulus *difference* of the two clusters. This difference is found to be $\Delta(m-M)° = 3^m.88 \pm 12$ (Tammann et al. 1979b) using brightest cluster members (Sandage and Hardy 1973), the ten brightest cluster members (Weedman 1976), the color-luminosity relation of E and S0 galaxies (Visvanathan and Sandage 1977; data from Persson et al. 1979), and Type I supernovae at maximum light (Tammann 1978). The corresponding ratio of linear distance is 5.97 ± 0.34, which requires a Virgo velocity of 1154 ± 65 km s^{-1}.

The *observed* mean recession velocity of the Virgo cluster is 950 ± 50 km s^{-1} (Kraan-Korteweg 1979); this and the combine evidence from (1) and (2) indicates then that the Local Group has a peculiar motion toward the Virgo cluster of 174 ± 74 km s^{-1}.

(3) An analysis of the magnitudes and velocities of the galaxies of the Revised Shapley-Ames Catalog (Sandage and Tammann 1980), making proper allowance for selection effects and all possible density fluctuations, yields a peculiar Local Group motion of $100 < v_{pec} \leqslant 200$ km s^{-1} in the direction of Virgo (Yahil et al. 1979); this result is derived by *excluding* the galaxies in the Virgo direction, and it is therefore fully independent of (1) and (2).

The small peculiar motion toward Virgo and the requirement of a reasonable luminosity function as well as other constraints (cf. Tammann et al. 1979) exclude the possibility of variations of H_o of the size proposed by the V scale. These arguments disprove also other claims of peculiar motions of the Local Group of the order of 500 km s^{-1}, either away from Virgo (Gudehus 1978) or toward Virgo (Huchra 1979). These claims are based on unreliable distance indicators, viz. the "knee" of the galaxian luminosity function and the width of the 21 cm-line, respectively.

In accordance with the only slightly disturbed local expansion field, the ST scale found nearly the same values for H_0 (local) and H_0 (global), i.e., $H_0 = 55$. (This value is almost automatically decreased to $H_0 = 50$ if van Bueren's Hyades modulus of 3.03 has to be increased by $\sim 0\overset{m}{.}2$.) The V scale requires $H_0 = 70$ within the Local Supercluster, and because it can be demonstrated by the arguments given above that H_0 does not appreciably increase beyond the Virgo cluster, the possible range of the global value of H_0 lies between 50 and 70. The higher value, as preferred by the V scale, comes already into the above-mentioned difficulty with recent data on the Cepheids in LMC and with the brightest stars in M101.

One can therefore be confident that with some more ground-based work the uncertainty of H_0 can be confined to $\sim\pm 15$ percent. Much of this work shall be concerned with the galactic absorption, the calibration and application of the period-luminosity-*color* relation of Cepheids, and an improved understanding of the biases of galaxy samples. The character of these problems does not make it evident how the Space Telescope could be used effectively for their solution.

3. PRESENT LIMITATIONS ON THE ACCURACY OF H_0

In the previous section it was argued that it is possible to determine H_0 (local) from the ground within $\sim\pm 15$ percent, and since stringent limits can be set on any large-scale non-linearity of the expansion field, the value of H_0 (global) can be obtained to almost the same accuracy.

Therefore if the Space Telescope is to be used for the determination of H_0, there must be justified hope that it can do considerably better, i.e., it must obtain H_0 to less than ± 10 percent.

Unfortunately there are intrinsic limitations to the accuracy with which H_0 can be determined. These limitations are largely controlled by the following three factors:

(1) Uncertainty of the local calibration: Because the Hyades modulus, on which essentially the whole Population I distance scale rests, is still uncertain at the 10 percent level, derived extragalactic distances cannot have smaller zero-point errors. The same error holds also for the Population II distance scale which is illustrated by the fact that presently quoted errors of the absolute magnitude of RR Lyr stars amount to $\pm 0\overset{m}{.}2$ (Sandage 1970; Hemenway 1975; Heck and Lakaye 1978; Pel and Lub 1978).

(2) Intrinsic scatter and instability of distance indicators used: The absolute magnitudes of known distance indicators have random variations of $\geq 0^m.2$ (an exception are the mean absolute magnitudes of RR Lyr stars and Cepheid luminosities derived from the period-luminosity-color relation), and the variation of standard diameters (H II regions) is even larger. In addition, some distance indicators are known to be unstable against changes in chemical composition.

(3) Random motions of field galaxies: The random motions of galaxies in the field can amount up to 50 km s^{-1} in the mean (cf. Tammann et al. 1979b), which immediately introduces at least a 10 percent uncertainty to H_o derived from the most accessible, nearby galaxies ($v_o \leq 500$ km s^{-1}).

The Space Telescope shall eventually help to improve the situation with problem (1). Problems (2) (at least in part), and (3) can be solved by averaging over many galaxies. But this requires very much observing time, which is further increased by the necessity to control the patchiness of the galactic absorption below $|b| \sim 40°$ (cf. Sandage 1976b) and within the parent galaxy.

There is hope that the Baade-Wesselink method applied to supernovae shall eventually yield distances to galaxies within $\leq$ 10 percent. Present results are encouraging (Kirshner and Kwan 1974; Branch 1977; Schurmann et al. 1979). But to derive H_o one shall turn to galaxies with $v_o \leq 5000$ km s^{-1}, which is clearly a task for ground-based work.

These views on the possibilities of the Space Telescope to improve the accuracy of H_o in a single program may be overly pessimistic. However, there is no question that it would be highly desirable to check the accuracy of the present distance scale with the Space Telescope. To this end two feasible programs are described in the following.

4. A CHECK ON THE DISTANCES OF NEARBY GALAXIES

The Space Telescope shall offer the opportunity to observe primary distance indicators to about ten times larger distances than previously possible. Two particularly important applications of this ability shall be briefly described.

4.1. RR Lyr Stars in M31

Except for a few dwarf spheroidal galaxies, extragalactic RR Lyr stars have been observed only in LMC (Graham 1973) and SMC (Graham 1975). At the apparent distance modulus of M31

$(m-M)_{AV} = 24^m.64$ (Baade and Swope 1963; Sandage and Tammann 1971), RR Lyr stars with a mean absolute magnitude of $\langle M_V \rangle = 0^m.5$ shall appear at $m_V = 25^m.14$ or at minimum light at $\leq 26^m.0$. At this magnitude the Wide Field Camera (WFC) yields an accuracy of $0^m.06$ within 1000 sec of integration. (The technical specifications of the WFC are taken from Westphal et al. 1978)

The search field should be placed along the minor axis on the far side of the galaxy and hardly nearer than 10 kpc from the nucleus; this is to guard against absorption effects and to stay outside the main image of the galaxy. Our Galaxy has at this radial distance ~1 RR Lyr star kpc^{-3} (Kinman 1972). If this is taken as representative for M31, one calculates an order-of-magnitude expectation of 8 RR Lyr per 0.27 kpc^2, corresponding to the field of the WFC at the distance of M31.

In principle it is not necessary to obtain periods of the RR Lyr stars because there is hardly a correlation between $\langle M \rangle$ and period. The detection of the variables and the establishment of their character would then require only ~5 exposures. However, to obtain some information on their Osterhoff type and metallicity, one still needs light curves and hence periods, perhaps even colors at minimum light. This requires at least 15 exposures well spaced in time.

The distressingly small number of variables in the WFC field makes it doubtful whether one search field is sufficient It may be necessary to search 2-6 fields, say ~3.

The total observing time required becomes then ~45,000 sec, or 22 x 2000 sec. A principal reason why this project is so expensive is, of course, the large angular extension of M31 and the relative scarcity of RR Lyr stars. For this reason the following program should be given higher priority.

4.2 Cepheids in M101

The distance of M101 is of fundamental interest for two reasons: (1) it is a member of a bona-fide group (Sandage and Tammann 1974b); therefore the *mean* group recession velocity of 368 ± 23 km s^{-1} (Tammann and Kraan 1978) should be essentially free of random peculiar motions, and it therefore provides a zero-point calibration of the local velocity field derived from relative distances only (cf. Section 5); (2) M101 is the brightest nearby Sc spiral; the reasonable requirement that the brightest corresponding Virgo cluster members must reach at least this luminosity, sets a lower limit to the cluster distance; in addition, the necessity of some distant

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field Sc's being brighter than M101 (cf. Section 2) yields immediately a maximum value of H_o (global).

Ground-based photometry down to $m_B = 22^m$ of 20 Cepheids in an outlying, nearly absorption-free field in M31 has reached to an apparent distance modulus of $(m-M)_{AB} = 24\overset{m}{.}8$ (Baade and Swope 1963).

An equally suitable field in M101, at a distance modulus of $(m-M)_{AB} = (m-M)^{\circ} = 29\overset{m}{.}3$, requires then photometry down to $26\overset{m}{.}5$ (corresponding to minimum light of the Cepheids). Scaling the frequency of Cepheids in M31 to a field of 14 kpc^2, corresponding to the WFC field at M101, gives a sufficient number of ~16 Cepheids. An accuracy of $0\overset{m}{.}1$ at minimum light would be satisfactory; this corresponds to an integration time of 720 sec.

In order to determine the widely different periods of Cepheids at least 25 B-exposures are needed. Because the period-luminosity-*color* relation requires additional color information, 10 V-exposures are also necessary.

The total observing time required is then found to be 26,000 sec, or 13 x 2000 sec. It is surprising that this program is almost certainly less demanding than the RR Lyr stars in M31.

From the case of M101 it is clear that the Cepheids in the Virgo cluster, still $2\overset{m}{.}2$ more distant, lie at the very limit of the Space Telescope. For three reasons the result could not possibly excel in accuracy: (1) Only m_B (max) can be hoped for, and therefore the relation of period and B_{max} has to be used (cf. Tammann and Sandage 1968); (2) the apparent advantage of larger numbers of Cepheids per exposure is offset by absorption and crowding effects; and (3) the mean Virgo cluster velocity has an inherent error of ± 50 km s^{-1} to which is to be added the error of our infall motion toward Virgo. For this reason alone any value of H_o derived from the cluster is inseparably inflicted with an error of ~10 percent.

5. THE MAPPING OF THE LOCAL VELOCITY FIELD

It was stated above (Section 2) that it is of paramount importance to map the local velocity field with relative distance indicators if one wants to transform one or several known values of H_o (local) into H_o (global). Since our local peculiar motion of 150 ± ~50 km s^{-1} toward Virgo is almost

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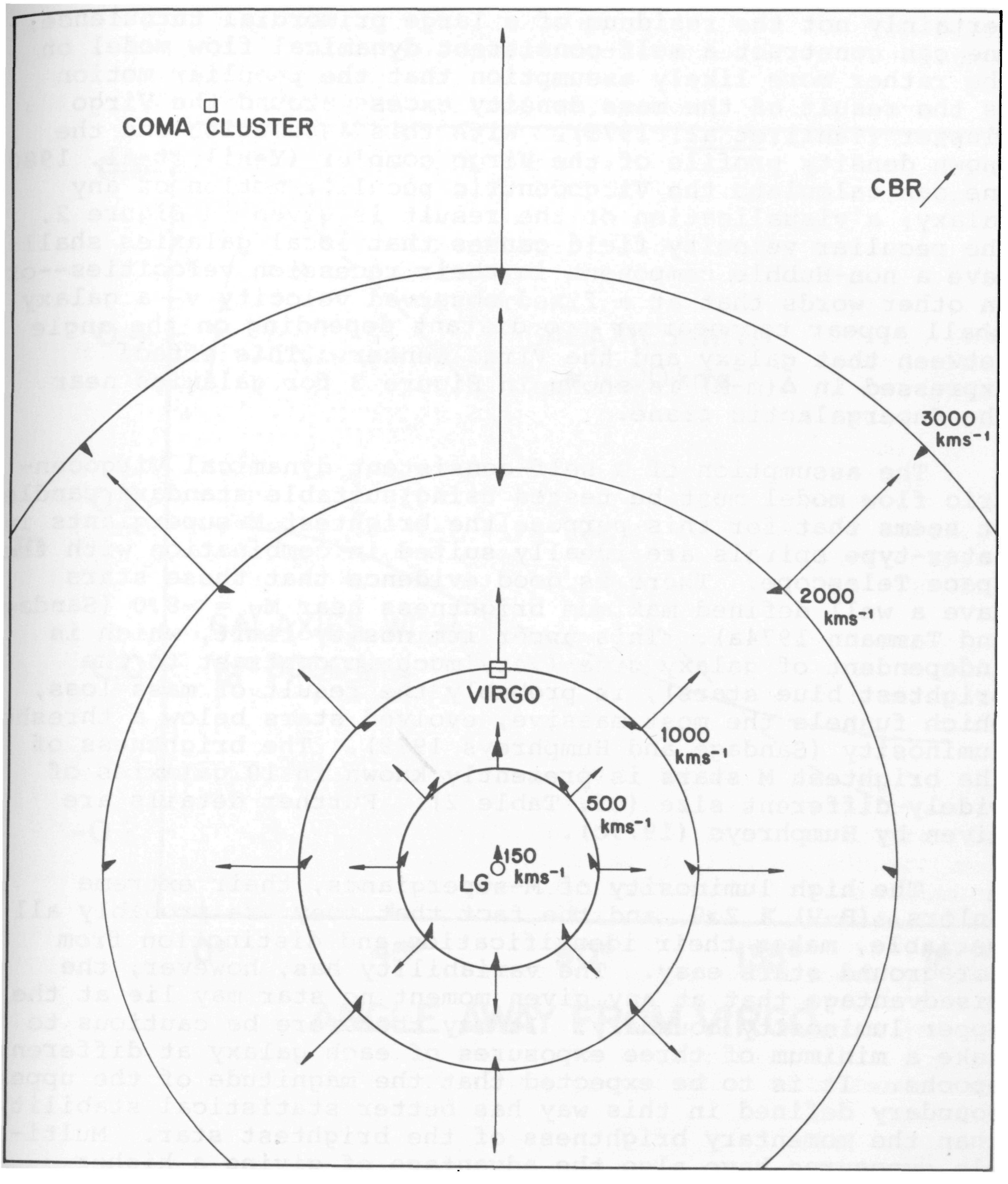

Fig. 2. Schematic presentation of the local velocity field in the Supergalactic plane. Thin arrows symbolize the ideal Hubble flow. Heavy arrows represent the overlaying Virgocentric flow; their length is calculated assuming a Local Group infall velocity of 150 km s^{-1} and a density profile of the Virgo cluster complex decreasing with r^{-2}. The random peculiar motions of individual field galaxies, $\leqslant$ 50 km s^{-1},

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certainly not the residuum of a large primordial turbulence, one can construct a self-consistent dynamical flow model on the rather more likely assumption that the peculiar motion is the result of the mass density excess around the Virgo cluster (Yahil et al. 1979). With this assumption and the known density profile of the Virgo complex (Yahil et al. 1980) one can calculate the Virgocentric peculiar motion of any galaxy; a visualization of the result is given in Figure 2. The peculiar velocity field causes that local galaxies shall have a non-Hubble component in their recession velocities--or in other words that at a fixed observed velocity v_o a galaxy shall appear too near or too distant depending on the angle between that galaxy and the Virgo center. This effect expressed in Δ(m-M) is shown in Figure 3 for galaxies near the Supergalactic plane.

The assumption of a self-consistent dynamical Virgocentric flow model must be tested using suitable standard candles. It seems that for this purpose the brightest M-supergiants in later-type spirals are ideally suited in combination with the Space Telescope. There is good evidence that these stars have a well defined maximum brightness near $M_V = -8^{m}_{.}0$ (Sandage and Tammann 1974a). This upper luminosity limit, which is independent of galaxy size (very much in contrast to the brightest blue stars), is probably the result of mass loss, which funnels the most massive, evolved stars below a threshold luminosity (Sandage and Humphreys 1979). The brightness of the brightest M stars is presently known in 10 galaxies of widely different size (cf. Table 2). Further details are given by Humphreys (1979c).

The high luminosity of M-supergiants, their extreme colors, (B-V) $\geqslant 2^{m}_{.}0$, and the fact that they are probably all variable, makes their identification and distinction from foreground stars easy. The variability has, however, the disadvantage that at any given moment no star may lie at the upper luminosity boundary. It may therefore be cautious to take a minimum of three exposures of each galaxy at different epochs. It is to be expected that the magnitude of the upper boundary defined in this way has better statistical stability than the momentary brightness of the brightest star. Multiple exposures have also the advantage of giving a higher

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are too small to be shown to scale. The distance to the Coma cluster is not to scale; it is shown only as an available reference point which is likely to reflect the cosmic expansion to within less than 10 percent. The 600 km s^{-1} velocity inferred from the anisotropy of the Cosmic Background Radiation (CBR) must comprise the whole volume shown.

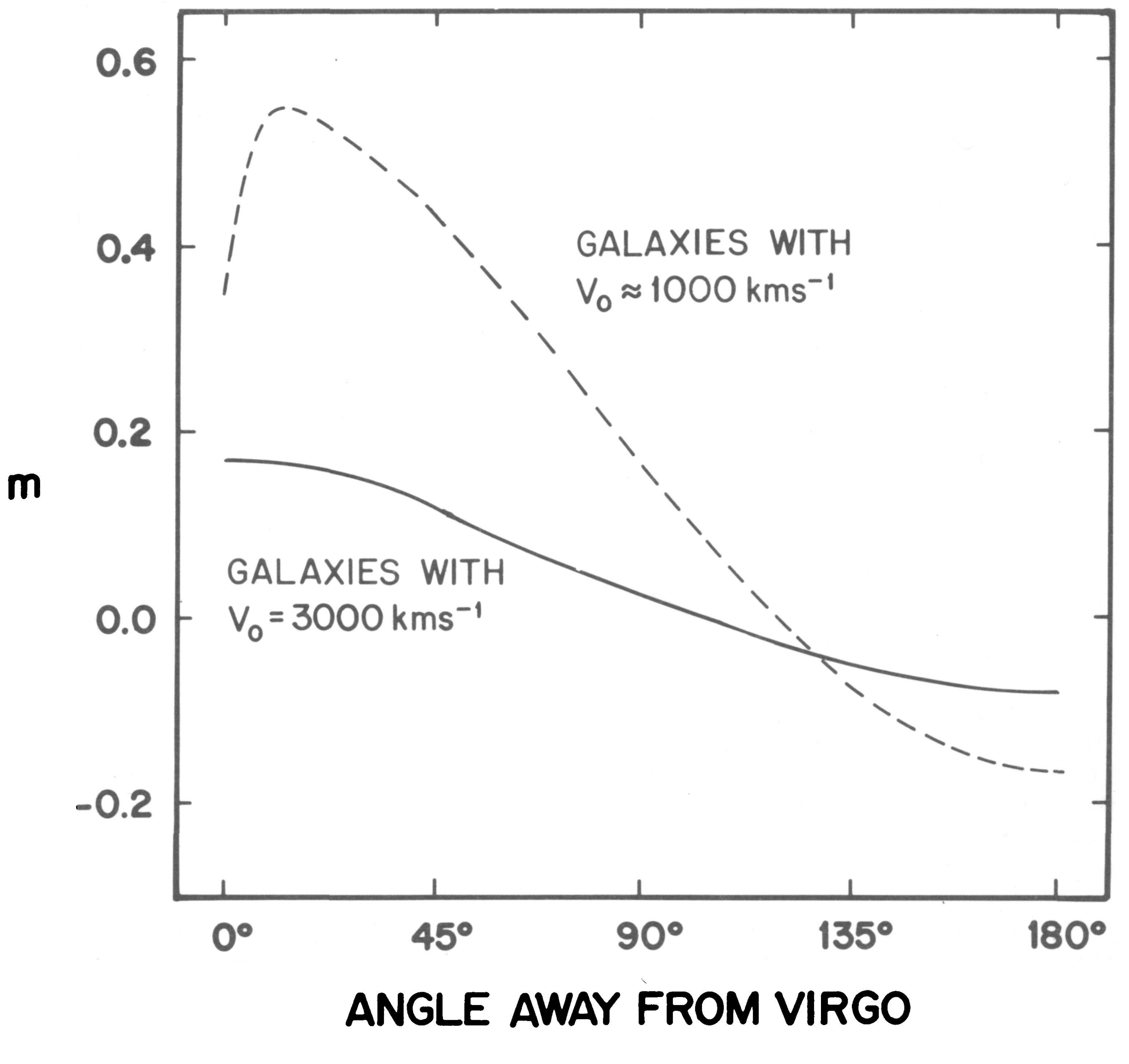

Fig. 3. The variation of apparent distance modulus in the Supergalactic plane for a fixed observed recession velocity. The values $\Delta(m-M)$ are roughly estimated from the Virgocentric flow model described in the text. The actual calculation shows that $\Delta(m-M)$ is multi-valued at small distances from the Virgo cluster.

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Table 2: Brightest M-Supergiants

Galaxy	M_V (max)	Source
Galaxy (μ Cep)	$-8^m_.2$	2
LMC	-8.1	1,3
SMC	-8.2	1,7
M33	-8.1	4
NGC 6822	-7.8	1
IC 1613	-8.03	1,5
WLM	-7.8:	6
NGC 2403	-7.8	1
IC 2574	-7.8:	1
Ho II	-7.4:	1
	$-7.9 \pm 0^m_.1$, $\sigma \approx 0^m_.25$	

Sources: 1, Sandage and Tammann 1974a; 2, Humphreys 1978; 3, Humphreys 1979b; 4, Sandage and Humphreys 1979; 5, Sandage and Katem 1976a; 6, Sandage and Katem 1976b; 7, Humphreys 1979a.

chance to the subsample of stars with small intrinsic absorption to appear at maximum; this is important because individual absorption corrections would pose additional problems.

The values in Table 2 were essentially derived without intrinsic absorption corrections. They come in addition from data with widely different time coverage. It can therefore be assumed that the upper luminosity shall be determined with only a few exposures to within $\sim 0^m_.2$. This makes the M-supergiants clearly powerful distance indicators.

At a velocity of v_o = 3250 km s^{-1} the M-supergiants appear at V = 26^m and B $\approx 28^m$. Good V-photometry ($\pm$ $0^m_.06$) can be obtained in 1000 sec of integration, and since the B-magnitude is only needed to ensure that (B-V) $\geq 2^m_.0$, about 2000 sec of integration in B are sufficient. The WFC covers at that distance the inner 25 kpc, i.e., essentially the whole optical spiral structure of even a large spiral galaxy and therefore almost the entire population of M-supergiants. This makes evident that these stars are ideally suited for the WFC: they are still accessible at distances where whole spiral galaxies can be sampled.

With 3 V- and a minimum of 1 B-exposures a galaxy at v_o $\approx$ 3000 km s^{-1} requires therefore 5000 sec. The expense for a galaxy at v_o $\approx$ 1000 km s^{-1} is about the same, because

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shorter integration times are compensated by the necessity of several frames (unless one chooses intrinsically smaller galaxies).

A program of 50 galaxies at $v_o \approx 3000$ km s^{-1} and 10 galaxies at $v_o = 1000$ km s^{-1}, well distributed over the sky, needs 150 x 2000 sec of integration time, which corresponds roughly to 14 days of the life of the Space Telescope. The obvious yield would be 10 percent limits on the random peculiar velocity components of individual galaxies, but because the random noise of their radial velocities is almost certainly $\leqslant 50$ km s^{-1}, large-scale streaming motions down to ~50 km s^{-1} could be detected. This shall give a unique possibility to improve the local Virgocentric motion, to test the assumption of a general Virgocentric flow model, to detect deviations from this simple model, and to determine the density parameter Ω/Ω_{crit} (cf. Yahil et al. 1979). It shall also set stringent limits on what fraction of the observed cosmic background anisotropy (cf. Smooth 1979; Wilkinson 1979) could be due to *local* shear motions. Finally it should be repeated that the mapping of the local velocity field is a prerequisite for a high-accuracy determination of H_o (global) from local distances.

The above considerations are somewhat pessimistic because M-supergiants were used only as *relative* distance indicators. Actually their maximum absolute magnitude is rather well determined, i.e., $\langle M_V(max) \rangle = -7^m.9$. Making reasonable assumption on the systematic errors, the external uncertainty of this value is $\leqslant 0^m.3$. With this information on their *absolute* luminosity, a number of them at $v_o = 3000$ km s^{-1} will directly lead to an estimate of H_o (global) to certainly better than 20 percent.

6. SUPERNOVAE AS STANDARD CANDLES

Present data suggest that SNe of Type I in E (and S0) galaxies are at maximum light very good standard candles. The observed magnitude dispersion amounts to $\sigma(m_{pg}) = 0^m.4$, but the true dispersion is certainly smaller and possibly vanishingly small (Tammann 1978). SNe I in other types of galaxies suffer from internal absorption, as do SNe II, and they exhibit therefore a much wider luminosity scatter at maximum (cf. also Branch and Bettis 1978).

The properties of brightest cluster galaxies are known to change with cosmic time which disqualifies them for the determination of q_o. Their role as standard candles could be taken over by SNe I in E/S0 galaxies, because the explosion of a Type I SN, whatever its origin may be, seems to be a physically well defined event, which is not expected to vary with time. However, SNe I are 3^m fainter at maximum than brightest cluster galaxies, and it is this property which makes them ideal objects for the Space Telescope.

The potentials of SNe as cosmological probes are apparent from Table 3, where some of their relevant properties are compared with those of brightest cluster galaxies.

Before pursuing the main line of our argument further, it is important to investigate if sufficient SNe I in E/S0 galaxies can be found at cosmologically useful distances, say at z = 0.5.

6.1 The SN Search

The faintest SN found so far from the ground has $\sim 20^m$. From this it is clear that SNe at 23^m, corresponding to the maximum magnitude at z = 0.5, must be searched with the Space Telescope! In that case one has to ask where the highest SN I frequency per $(\text{arcmin})^2$ can be expected. This is clearly in rich clusters. These clusters have in addition the most welcome property of providing almost exclusively the subtype of SNe of interest here: with essentially only E and S0 galaxies these clusters cannot yield anything but absorption-free SNe I. There is yet another advantage to concentrate on clusters: if the parent galaxy of a SN happens to be too faint to obtain its redshift--from the ground or from the Space Telescope--the cluster redshift can also be obtained from the brightest cluster members. Moreover, the clusters and hence the SNe can be *pre*selected according to redshift.

At z = 0.5 the field of the WFC corresponds to a circle of 0.64 Mpc radius ($q_o = 0$). Within that radius a cluster like Coma contains $5 \cdot 10^{12}\ L_\odot$ (Abell 1975; Rood et al. 1972; King 1972). The SN frequency in E/S0 galaxies is 0.16 SNe $(10^{10}\ L_\odot)^{-1}\ (100\ \text{yr})^{-1}\ (1 + z)^{-1}$ (Tammann 1978) or 0.5 SNe I per year per cluster at z = 0.5 (with the reasonable assumption that the SN I frequency has remained essentially the same during the last few billion years). A Space Telescope survey of 50 Coma-like clusters at z = 0.5 (admittedly a sample size which is *presently* not available) would therefore yield 25 SNe I per year with an estimated uncertainty of a factor 2.

From the standard B-light curve of SNe I (Barbon et al. 1973), one finds that a SN remains within 1^m of its maximum

Table 3: First-Ranked Cluster Galaxies and SNe I in E/S0 Galaxies as Standard Candles

	First-ranked gal.	SNe I (in E/S0)
difficulty of photometry of extended obj.	yes	no
luminosity evolution	yes!	no (?)
dynamical evolution	yes	no
selection effects (Malmquist bias)	yes (?)	controllable[1)]
imperfect imaging of a realistic universe[2)]	yes	little
intergalactic absorption	yes	yes
M_V(max)	$-23^m.0$	$-19^m.7$
$\sigma(M_V)$	$0^m.3$	$0^m.4$!
$(B-V)_{max}$	$1^m.0$	$-0^m.15$
at z = 0.25		
m_V(max)	$17^m.6$	$21^m.1$[3)]
$(B-V)_{max}$	$1^m.6$	$0^m.0$[3)]
at z = 0.5		
m_V(max)	$20^m.5$	$22^m.9$[3)]
$(B-V)_{max}$	$1^m.3$	$+0^m.15$[3)]

1) At least in principle a comparison between expected and observed SN numbers yields the influence of any possible magnitude bias. In addition the search is planned here to detect *all* SNe I.

2) Cf. Zeldovich 1964; Kantowski 1969; Dyer and Roeder 1973; Refsdal 1970. In the absense of background the effect on the photometry of point sources is smaller.

3) Assuming $q_o = 0$, the approximate K-correction is calculated assuming an energy distribution of a black-body of 10,000 K. Due to cooling the K-correction increases strongly after maximum: 15 days after maximum (~8000 K) a SN at z = 0.5 shall therefore decrease not by $1^m.0$, but rather by $1^m.4$, and it shall have (B-V) ≈ $0^m.3$.

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brightness for 25 (1 + z) days, i.e., at z = 0.5 it is brighter than 24^m for 38 days. About 40% of all SNe I with $m_B < 25^m$ discovered at z = 0.5 shall be at pre-maximum; for the remaining 60% the maximum B-magnitude can be restored within $\sim 0.2^m$ from the standard light curve. It is therefore sufficient if each cluster is searched--yielding ample margin--down to 25^m once per month. Because of the high temperature of SNe at maximum and because of the background light of the parent galaxy, it is advantageous to conduct the search in blue light.

A 25^m object can be detected with the WFC with a signal-to-noise ratio of 7 within 100 sec of integration. The background noise of the parent galaxy shall reduce the photometric accuracy, especially in the inner regions, but it shall hardly affect the discovery chance. Therefore 12 100 sec-exposures of each of the 50 clusters, resulting in 25 sufficiently fresh SNe I, will require 30 x 2000 sec of actual observing time, which corresponds roughly to 4 days of telescope time. This is indeed a modest price for the goals described in the following.

6.2 The Hubble Diagram of SNe I

The apparent magnitude of standard candles at z = 0.5 differs by $0^m.25$ for the case $q_o = 0$ and $q_o = 0.5$ (Sandage 1961). If the intrinsic magnitude dispersion of SNe I at maximum is $0^m.2$, then it is possible to distinguish with only six SNe between a Euclidean and an open universe at the 3 σ level. Even if the intrinsic dispersion were as high as $0^m.4$ the same result could be obtained from 25 SNe.

It should be noted that the determination of q_o from the Hubble diagram requires only apparent magnitudes (in addition to redshifts) and that it is therefore independent of H_o. However, it is *not* sufficient to have a number of SNe at z = 0.5 to determine the curvature of the Hubble line. Rather a number of SNe at small and intermediate redshifts with uniform photometry are needed in addition. The search for these additional SNe I in E/S0 galaxies shall turn out to be quite time-consuming, regardless if performed from the ground or with the Space Telescope. The presently known 14 SNe I with m(max), which occurred in E/S0 galaxies, define the zero-point of the Hubble line only to within $\sim 0^m.2$ (Tammann 1978). The details of an optimum observing programme are still to be devised.

A minor difficulty is that at present the time-variable K-correction of SNe is not known. It would be important to

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obtain the ultraviolet spectra, possibly with IUE, of a nearby Type I SN during an interval of ~25 days around maximum light. This would also be important for the determination of the optimum wavelength of the precision photometry which must follow the discovery. This photometry, possibly performed with the Faint Object Camera, is necessary to determine the exact phase and to inter- or extrapolate the maximum brightness.

6.3 SNe I as Non-Standard Candles

The increasing potentials of the Baade-Wesselink method applied to SNe have been mentioned above (Section 3). The application of this method of SNe at higher redshifts has most recently been discussed by Oke (1979) and Wagoner (1979).

Suffice it to mention that two spectra with resolution 10^3 could be obtained with the Faint Object Spectrograph of a SN I at z = 0.5 about a week after maximum (23ᵐ5) within 2 x 12^h.

The principal difference of this approach toward q_o and the route via the Hubble diagram is that the Baade-Wesselink method gives a proper-motion distance and hence a value for q_o for every single SN, and that in addition the assumption of SNe I being standard candles can be dropped. The price for this is, of course, a full understanding of SN atmospheres and long integration times of the spectrograms.

7. CONCLUSIONS

The Space Telescope shall eventually improve the Galactic distance scale which shall influence also the calibration of extragalactic distances. It should observe RR Lyr stars in M31 and more importantly Cepheids in M101 to check the present distance scale at the ~15 percent level.

The brightest M-supergiants, which can be observed with the Space Telescope out to $v_o \approx 3000$ km s^{-1}, shall provide an excellent relative mapping of the local velocity field. Knowledge of this field is important to determine H_o (global) as function of position and H_o (local); but it is not clear, whether the Space Telescope shall play a decisive role in providing an improved zero-point calibration of the expansion. However, the relative velocity field shall also yield an accurate determination of the density parameter Ω/Ω_{crit}.

A unique chance to determine q_o from the Hubble diagram of SNe I out to z = 0.5 is offered by the Space Telescope.

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If, however, the expectation that SNe I in E galaxies are nearly perfect standard candles should prove wrong, q_o could still be obtained via the Baade-Wesselink method applied to SNe. The photometry of SNe I at z = 0.5 at the rest-wavelength of the B-filter would, in addition, yield a fundamental test on the Doppler nature of redshifts (Tammann 1979).

Since the Space Telescope shall improve the determination of Ω and measure q_o, it affords a comparison of these parameters which shall set limits on the smoothly distributed invisible mass in the universe or/and on the cosmological constant Λ.

These notes were written while the author was a guest at the Hale Observatories. He thanks the Director, Dr. M. Schmidt, and the Staff for their hospitality. He thanks Dr. A. Sandage for many stimulating discussions. He acknowledges support from the Swiss National Science Foundation.

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DISCUSSION

van Woerden: 1. In the derivation of the infall of the Local Group towards the Virgo Cluster, you assume that the properties of galaxies in the field and in the Virgo and Coma Clusters are the same. Should one not expect that these properties will depend on the environment ?

2. You accept a sharp cutoff at M = -8.0 for red supergiants, but reject a cutoff in the absolute magnitudes of galaxies in your comparison of the Sandage-Tammann and the Vaucouleurs distance scales. To what extent is this justified ?

Tammann: 1. Yes. However, we have made very careful comparisons of the properties of E and SO galaxies in these clusters. In particular the luminosity functions of the E and SO galaxies follow exactly the same Schecter luminosity function.

2. M supergiant stars are good distance indicators because there are good physical reasons why they cannot be brighter than M = -8. Mass loss prevents it.

Spinrad: If you measure the light curves of supernovae well enough, you can find a redshift from the time dilation.

Tammann: Yes. This also provides a direct test of the nature of redshifts.

Oke (Discussion leader): I will discuss the Baade-Wesselink method of distance determination which avoids the various steps discussed by Dr. Tammann in his presentation. The method was first applied to Cepheids : you have to measure three things, the velocity of the expanding atmosphere or envelope and the flux per cm^2 at two different times through the surface of the star. If the atmosphere of the expanding envelope is understood, the change in flux is related to the change in radius of the star and consequently its distance can be found. This has already been attempted for supernovae with encouraging results. However, the method needs to be perfected and I will discuss some of the problems.

The expansion velocity of the envelope is determined from the emission lines in the optical spectrum. The lines are broad and have characteristic P-Cygni profiles. To interpret them in terms of expansion velocities needs good model atmospheres. Type II supernovae are good in this respect because their spectra are reasonably well understood. The spectra of Type I supernovae are less well understood. It may be possible to make UV observations from IUE or ST to use the MgII 2800 Å line which may be free of blends.

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To evaluate the surface flux, one works out the effective temperature and uses a model atmosphere to find the total emitted flux. So far the visible and near infrared wavebands have been used to measure the spectra and the energy distributions are similar to black bodies. In the UV, the recent Type II supernova in M100 was observed by IUE and the UV spectrum agreed well with a black body model atmosphere. For Type I supernovae, further observations will be necessary with IUE and ST to find out how well the model atmospheres can account for the observations. Good model atmospheres for these expanding envelopes will be needed.

Dr Wagoner will describe more details of this technique.

Wagoner: I would like to discuss briefly why the space telescope could allow us to make full use of the advantages of supernovae as distance indicators. The basic idea was introduced by Walter Baade in 1926, and its application to supernovae was first suggested by Leonard Searle. Estimates of the Hubble constant were first obtained from Type I supernovae (SNI) by Branch and Patchett in 1973, and from Type II supernovae (SNII) by Kirshner and Kwan in 1974.

There are two basic advantages to the use of supernovae as probes of the Universe. First, they may be physically simpler systems than galaxies. Second, this kinematical method of determining distance avoids the need to invoke assumptions about the intrinsic properties of the probe (such as its luminsoity or size) which can only be indirectly tested by observation.

The main assumption involved in this method is that the nature of the photosphere is understood in terms of a model atmosphere. In particular, if the photosphere is spherically symmetric and sharp (optical depth $\tau \propto r^{-n}$, $n >> 1$), the (proper motion) distance to the SN is given by

$$d_M = (c/H_o)Z[1 - 0.5(1+q_o)\, Z + O(Z^2)] = v_*(d\theta/dt)^{-1} \, .$$

The photospheric velocity v_* is determined from the line profiles, and the effective angular size θ from the ratio of observed to emitted flux. Since the P Cygni type lines are better identified and the continuum is better defined in SNII, the method is most easily applied to them. In any case, the assumed model atmosphere is tested by a) the detailed frequency dependence of the observed flux, and b) the predicted constancy of $v_*(t)(d\theta/dt)^{-1}$. In fact, from (b) it is known that the assumption of a sharp photosphere breaks down about one month after maximum brightness. Therefore, absolute spectrophotometry of the supernova is required at least once a week before that time.

It might be thought that the use of SNI would have the advantage that a) they are 1-2 magnitudes brighter at maximum, and since they occur in elliptical galaxies, b) less absorption is expected and c) the search of rich clusters with the wide-field camera on the space telescope (at redshifts $Z \gtrsim 0.3$) would preferentially find them. However, SNI and SNII are equally bright ($M_B \sim -17$) after a few weeks, when observations are still required, so that (a) is only relevant to discovery. Secondly, there are indications that a significant fraction of SNII may have little absorption, and this can be determined from good spectra. Finally, the results of Butcher and Oemler indicate that distant rich clusters may have a higher fraction of galaxies in which SNII are expected.

The space telescope becomes absolutely essential in determining q_o by this method. The basic reason is the fact that for redshifts $Z \gtrsim 0.1$, resolutions less than 1 arcsec are required to exclude the galactic background flux. At a redshift $Z = 0.3$, a SNI or SNII with little absorption will have reached $m_V \sim 23$ after a few weeks. This corresponds to the limiting magnitude of the space telescope faint object spectrograph with wavelength resolution $\lambda/\Delta\lambda = 10^3$ and $S/N \sim 10$ for 5 orbits of observation.

The detection of SN of redshift $Z < 0.3$ may best be carried out from the ground. The rate of occurance of either type with redshifts $\leq Z$ in a Schmidt field ($6^o \times 6^o$) should be $dN/dt \sim 100\, Z^3$ per week for $Z << 1$. Plate scanners and digitizers such as those being developed by Ed. Kibblewhite could detect the changes in luminosity and/or shape of a galaxy due to a SN event at such redshifts. It is a fortunate coincidence that the relatively small field of the wide field camera on the space telescope can however encompass a rich cluster of galaxies at redshifts $Z \gtrsim 0.3$.

The implementation of this program to use supernovae as distance indicators should proceed in three stages :

1) More theoretical study and construction of model supernova atmospheres. Ground-based observations of SNII with redshifts $Z \lesssim 0.01$ to test the model atmosphere.

2) Ground-based (and/or space telescope ?) observations at redshifts $0.01 \lesssim Z \lesssim 0.1$ to determine H_o.

3) Space telescope observations at redshifts $Z \gtrsim 0.1$ to determine q_o.

A vital part of this program is the initiation of systematic searchs for supernovae of the required redshifts. It would appear to be worth the effort, since this method involves no evolutionary effects, selection effects, or the need for many objects.

A more detailed discussion of this approach to the determination of cosmological distances will be published in Comments on Astrophysics and the Proceedings of the 1979 Les Houches Summer School on Physical Cosmology.

Kirschner: In addition to being tools for cosmology, supernovae are of interest and importance in their own right. Particularly interesting will be observing them to their very faint later stages where we may learn something about what is inside them. In addition UV observations of both Types of supernovae will be very interesting. The IUE observations by the European observers show how much of importance about the supernova atmosphere can be learned and this should be extended to Type I supernovae with IUE and ST.

Macchetto: It is true that the continuum radiation of the supernova in M100 agreed with a black body according to our IUE observations but there are problems. The UV lines gave initially velocities of about 4000 km s^{-1} but when the optical lines developed the velocites were twice this value. This means that supernovae of Type II are not simple objects and better models are needed. It also illustrates the importance of ST because IUE can only observe the very brightest extragalactic supernovae whilst ST can go to very much fainter magnitudes. Also UV observations of the CIV as well as the MgII lines will prove important diagnostic tools for velocities of expansion.

Humphreys: In their recent series of papers on the determination of the Hubble constant, Sandage and Tammann found that the luminosities of the brightest blue stars are dependent upon the luminosity of the parent galaxy - the more luminous the galaxy, the more luminous the brightest star. Their preliminary results for the red stars suggested that they may have a maximum luminosity near $M_V \approx -7^m.9$ which is independent of galaxy type, contrary to the results for the brightest blue stars. Consequently, the M supergiants might be useful as distance indicators.

I have been observing the individual brightest stars of all spectral types in nearby galaxies. The emphasis of this program is on the calibration of these most luminous stars as extragalactic distance indicators and on the physical characteristics and evolution of the most massive stars in galaxies of different types. Spectra for classification and photometry have been obtained for candidate supergiants in the Local Group galaxies, M33, M31, IC 1613, NGC 6822, the LMC and SMC, and the Milky Way. Most recently spectra have been taken of the brightest blue stars in M 101 and NGC 2403.

When I began these observations, the only known (spectroscopically) M supergiants were in our own galaxy. For that reason, much of the observing program has concentrated on the confirmation of the M supergiants and the determination of their luminosities in a variety of different galaxies.

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The results for the M supergiants, in all of the Local Group galaxies studied, show that the brightest red stars will be excellent distance indicators.

The supergiants in the solar neighborhood were first surveyed to provide a reference population for comparison with the results for other galaxies. The luminosities of the brightest stars in our galaxy are determined from their membership in associations and clusters.

Although a large body of data already exists in the literature for the early-type supergiants in the LMC, very little was known about the red supergiants. Spectra and photometry were obtained for a large number of red stars in the LMC; 54 were confirmed spectroscopically to be M supergiants.

Spectra and photometry have also been obtained for the much fainter suspected M supergiants in the more distant Local Group galaxies - M33, IC 1613, NGC 6822. The brightest red stars have photographic magnitudes of $B \approx 19^m - 19^m.5$. Because the exposure times are long (4-m KPNO) fewer stars have been observed in these galaxies.

	# red stars observed	confirmed M supergiants
M33	33	12
IC 1613	3 (all variables)	3
NGC 6822	16	8

The observed magnitudes of all of the M supergiants were corrected for interstellar extinction and combined with the true distance moduli (from Cepheids) of the galaxies to derive their luminosities. The brightest red stars have maximum visual luminosities of $M_V \approx -8^m$ which is independent of galaxy type or the luminosity of the galaxy.

My observations in the SMC are not yet complete, but the preliminary results also suggest that the brightest red stars will be near $M_V = -8^m$.

Summary of Calibration for M Supergiants

	First Brightest	Three Brightest
Galaxy	-8.2	-8.0 ± 0.2
LMC	-8.1	-8.0 ± 0.1
M33	-8.4	-8.2 ± 0.2
NGC 6822	-8.0	--
IC 1613	-8.1	--

These results for the M supergiants in different types of galaxies

https://doi.org/10.1017/S0252921100111030 Published online by Cambridge University Press

with a wide range of luminosities yield a very tight luminosity calibration for the brightest M supergiants of $M_V = -8 \pm 0.2$. There also appears to be little or no dependence on the metal abundance of the galaxy (LMC and SMC).

On the basis of these results I suggest that the brightest M supergiants will be excellent distance indicators for spiral and irregular galaxies for the following reasons :

1) $M_V = -8^m$ is very tight; no dependence on galaxy type, no dependence on metallicity.

2) They are easily identified -- very red color (two-color photometry helps, B-V + V-R or B-V + V-I). Also most are variable which helps identification.

3) They are 2 magnitudes brighter than brightest Cepheids.

With the space telescope the M supergiants should be especially useful as distance indicators. With imaging to $V \lesssim 28^m$ the M supergiants could be identified in galaxies as distant as $(m-M)_V \lesssim 35^m$ (100 Mpc). With the faint object spectrograph spectra would even be possible to distance moduli of $(m-M)_V \lesssim$ (10 Mpc) which would include M 101.

In a collaborative program with Steve and Karen Strom to study the stellar content of M 101, we have tentatively identified the M supergiants The brightest candidates have V magnitudes of $\lesssim 21^m$ which with $M_V \lesssim -8^m$ gives a distance modulus of $+29^m.0$ for M 101.

In addition to the red stars, the brightest blue stars have also been observed in these same galaxies. The spectra and photometry for these stars confirm the Sandage and Tammann result that the luminosity of the brightest blue star depends on the luminosity of the galaxy. Because of this dependence on the luminosity (or type) of the galaxy the brightest blue stars are not as good distance indicators as the red stars.

It is worth mentioning that the visually brightest blue supergiant is a late B or early A-type star in all of these galaxies.

I recently obtained spectra of the brightest blue star candidates in the more distant spiral galaxies M 101 and NGC 2403. These are the first spectra of individual stars outside our Local Group. Four stars in NGC 2403 and three in M 101 are confirmed to be members. The visually brightest stars in both galaxies are A-type supergiants, and their spectral characteristics are consistent with the luminosities derived from their membership in M 101 and NGC 2403. The visual luminosities of the A-type supergiants are -9.4 for the one in NGC 2403 and -10.3 and -10.1 for the two in M 101. These two supergiants in M 101 are the visually brightest normal stars yet known in any galaxy.

Huchra: I'd like to talk about some work that throws a monkey wrench into the relatively smooth, undisturbed picture of the Hubble flow.

The Tully-Fisher relation is essentially the correlation between the absolute luminosity of a spiral galaxy and the width of its 21-cm neutral hydrogen profile. This correlation is strong and was used by the above authors to derive a distance to the Virgo cluster relative to local group galaxies. Its physical bases are the connection between the mass of a spiral galaxy and its maximum rotational velocity plus a relative constancy of the mass to light ratio.

After its initial application using blue luminosities, a number of objections were raised by other galaxy distance measurers, notably Sandage and Tammann, concerning problems of internal absorption corrections to the luminosities and differences of stellar content in spirals. A year ago my co-workers, M. Aaronson and J. Mould and I decided to see if these problems could be minimized by using infrared (1.6 μ) magnitudes instead of blue magnitudes. This worked exceedingly well (Ap. J., 226, 1, 1979) - the infrared colors of almost all galaxies are very similar, so the population measured is similar, and the extinction in the 1.6 μ band is only 0.07 of that in the blue, substantially reducing absorption corrections to the luminosities of edge-on galaxies. Note that edge-on systems are preferred for measuring 21-cm profile widths because the inclination corrections become negligible. The scatter in the relation was reduced to 0.3 magnitudes, making the infrared Tully-Fisher relation an ideal method for determining distances to galaxies and clusters of galaxies. We dervied initial values of 67 and 58 km $s^{-1}Mpc^{-1}$ for the Hubble constant using the Virgo and Ursa Major galaxy complexes, in good agreement with Sandage and Tammann.

In the past year we have improved the precision of the local calibration with large aperture photometry of nearby galaxies with the KPNO 0.075 m and obtained additional data for Virgo. Our distance moduli for galaxies in the M81, M101 and Sculptor groups - based on the Sandage and Tammann (hereafter ST) zero point for M31 and M33 agree exceedingly well with theirs, and our recalibration of the Virgo modulus with double the number of galaxies gives a Hubble constant of 62 ± 5 km s^{-1} Mpc^{-1}, in very substantial agreement with the ST value of 55 km s^{-1} Mpc^{-1}.

The problem arises with values derived for more distance clusters. Using radio data for six clusters at velocities of 4-7000 km s^{-1} from Sullivan and Schommer and from Chincarini and collaborators, we have derived a mean value of the Hubble constant of ∿ 90 km s^{-1} Mpc^{-1}. These clusters are scattered around the sky and are of a variety of morphological types. We have considered the possible systematic measuring effects and these cannot explain the discrepancy. The simplest hypothesis is that we are falling towards the Virgo complex with a peculiar velocity of 400-500 km s^{-1} - a velocity comparable to that seen in the recent microwave background anisotropy experiments, but substantially larger than the 175 km s^{-1} seen in the local galaxy samples by Sandage, Tammann and Yahil. Thus, I think the problem of the local motion appears not to be as simple as Tammann has just stated.

In closing, I would like to point out that although Space Telescope will not be useful for the measurement of global galaxy properties used here, its superb capability in the IR and near IR can substantially aid in the reduction of systematic errors in the local distance scale derived from stellar (Cepheid, RR Lyrae and Red Giant) calibrations by reducing the effects of both interstellar absorption and metallicity on the derived magnitudes of the calibrating stars.

Freeman: The Fisher-Tully relation in the Aaronson et al. form is $L \sim V^4$ which means constant mean surface density Σ from galaxy to galaxy. If this constant Σ changes from local calibrators to one cluster sample to another sample, then the zero point of the F-T relationship will change, and the luminosities derived will be systematically in error. For example, if the cluster spirals are systematically 0.5 mag different in Σ (compared to the calibrators), then the corresponding cluster distance will be wrong by 25%. Someone (I can't recall who!) has recently suggested that the Virgo spirals are systematically higher in surface brightness than spirals in the field. If the cluster environment, or anything else, affects the mean surface density of its spirals, then the F-T method will not be a reliable way to measure even relative distances for clusters.

Huchra: I think that the fact that we observe clusters of different morphology (concentration), some of which are very close to each other, and get approximately the same answer for all indicates that this problem may not be important.

Gunn: There are some spiral galaxies with rotation curves which seem to go on and on at roughly 230 km s^{-1} to 60 to 80 kpc. Have you looked into what these galaxies do to the Tully-Fisher relation ?

Rubin: The answer seems to be that if you stick to a single Hubble type, everything is all right. I would like to make two other comments. First, I would like to repeat a comment I made in 1961 at the Santa Barbara galaxy conference. Velocities in the S.A. catalogue can have errors as large as ± 300 km s^{-1}. Some velocities come from a single plate by Sinclair Smith at 1000 Å mm^{-1}. I hope before space telescope observations are undertaken that velocities of nearby galaxies will be available to higher accuracy.

Second, evidence that the expansion of the universe is smooth comes mostly from adopting as the distance of a galaxy the value v/H. The opportunity to discover a possible irregularity may depend upon a very special circumstance. Possibly one such circumstance is the Perseus cluster of galaxies, with a string of galaxies with < V > near 5000 km s^{-1} extending west from NGC 1275 (Perseus A), and a tighter group of galaxies with v near 8000 km s^{-1} to the NE of NGC 1275. At NGC 1275, we see both velocities, 5000 to 8000 km s^{-1}, with evidence from the 21-cm absorption line that the 8000 km s^{-1} gas is in front of the 5000 km s^{-1} gas. Could we be seeing 2 clusters, with the V = 8000 km s^{-1} cluster in front of the V = 5000 km s^{-1} cluster ? I don't know, but we ought to be alert to the possibility.