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Influence of a partial incompleteness of the sample on the determination of the Hubble constant

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Abstract. This paper presents a study of the Malmquist bias effect in the determination of the Hubble constant from the method of "sosies" (look-alike) galaxies. It is shown that a bias appears when a partial incompleteness exists in the sample. A new method, based on the use of the completeness curve, is proposed to correct for such a bias. After this correction, the Hubble constant drops of about 20% just because of the existence of the partial incompleteness. From the present results and on the acceptance of the distance modulus of primary calibrators, the value of the Hubble constant would be: $H_o \approx 60 \mathrm{km\,s^{-1}\,Mpc^{-1}}$ with an internal statistical error of about $2 \mathrm{km\,s^{-1}\,Mpc^{-1}}$.

Key words: distance scale – methods: data analysis – galaxies: general

1. Introduction

Determination of the Hubble constant, the ratio of the cosmological velocity to the distance of an extragalactic object, is one of the most vexating problems in observational cosmology. It is not possible to quote all references about this subject but many good review papers were published recently on this topic (see e.g. Jacoby et al. 1992; Van den Bergh 1992; Vaucouleurs 1993; Sandage, 1994). Even if one can consider that the Hubble constant is roughly in the range 50 to $100 \mathrm{km\,s^{-1}\,Mpc^{-1}}$, there is no consensus so far on a given value. It would be presumptuous to pretend solve this problem. At least we hope to provide some clues toward a better understanding of biases on this fundamental parameter.

The most difficult part in the determination of H_o obviously is the measurement of distances. Indeed, radial velocities can be measured very accurately (from radio observations the standard deviation on radial velocities can be less than $10 \mathrm{km\,s^{-1}}$) although the individual dispersion of velocities and evidence of large scale motions (Shaya 1984; Tammann & Sandage 1985; Burstein et al. 1986; Dressler et al. 1987; Lynden-Bell et al. 1988) prevent us from drawing an accurate value of H_o. The most powerful method to derive distance of spiral galaxies is given by the Tully-Fisher relation (Tully & Fisher 1977), a tight linear correlation between the rotational velocity and the absolute magnitude. The rotational velocity can be estimated from the 21-cm line width. Then, the knowledge of the absolute magnitude and the measurement of the apparent magnitude lead to the distance modulus which can be written as:

$$\mu = B_o - a \log(\frac{W_c}{2.\sin i}) - b \quad (1)$$

where B_o is the total blue magnitude corrected for inclination and galactic extinction effects (Bottinelli et al. 1995, Paturel et al., 1996), W_c is the 21-cm line width corrected for turbulent velocities and redshift effects and i is the inclination (angle between the line of sight and the polar axis) derived from the axis ratio of external isophotes (e.g. R_{25} at the brightness level of 25 mag arsec^{-2}). The two constants a and b which actually determine the TF relationship, are generally obtained from calibrating galaxies.

This method seems very simple but it hides many problems.

- Is the Tully-Fisher relation linear (Aaronson et al. 1979; Rubin et al. 1980; Bottinelli et al. 1983)?
- Do a and b depend on the morphological type T (Roberts 1978; Giraud 1985; Bottinelli et al. 1986; Theureau et al., 1996)?
- How to derive the inclination from R_{25}? What is the morphological type dependence (Heidmann et al. 1972, Fouqué et al. 1990)?
- How to correct W_c for turbulent velocities (Roberts 1978; Bottinelli et al. 1983; Tully & Fouqué 1985)?
- How to correct the apparent magnitude for inclination effect (Holmberg 1958; Heidmann et al. 1972; Sandage & Tammann 1976; Bottinelli et al. 1983; Bottinelli et al., 1994)?
- What is the proper slope to be used to avoid bias? (Schechter 1980; Tully 1988; Teerikorpi 1990).

In 1984, we proposed (Paturel 1984) a method to bypass most of these difficulties. This method (method of "Sosies galaxies" [1]) consists in selecting those galaxies which have the same

[1] This is a French expression which can be translated as "look-alike galaxies"

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parameters W_c, T, R_{25} as a calibrating galaxy. We can see easily from Rel. 1 that the distance modulus of such galaxies can be derived directly from the following relation:

$$\mu = \mu^{calib} + B_o - B_o^{calib} \tag{2}$$

(in this relation the quantities refering to the calibrating galaxy are noted with an upperscript "calib"), without considerations about the slope of the TF relation, the inclination, the morphological type dependence. Using this method in 1984 we found $H_o \approx 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and naively thought that the problem of the Hubble constant was solved, but soon after, Teerikorpi (1984) showed that even the method of Sosies galaxies is affected by the Malmquist bias. The completeness of the sample is one of the preliminary conditions to cope with biases. Because it is difficult to get a volume-limited sample, we generally use a magnitude-limited sample. But it is not so obvious to define such a complete sample (hereafter, *complete* will be understood as magnitude-limited sample). We discussed the completeness curve $\log N(B < B_{lim})$ *vs* B_{lim} in previous papers (Garcia et al., 1993; Paturel et al., 1994). The main result is that the slope in the linear part of the curve is not equal to 0.6 as expected for a homogeneously populated universe. At least three interpretations of this fact can be proposed:

- The sample is not complete and galaxies are progressively missed. The larger the distance the higher the number of missed galaxies.
- The distribution of the local Universe is partially flat.
- The distribution of galaxies is fractal.

All these hypotheses have been analyzed. The conclusion was that the flatness of the local universe is real due to the presence of the Local Supercluster. However, outside this flat region the curve does not reach either the canonical value 0.6. This suggest that the full completeness is not satisfied. We will call this the *partial incompleteness*.

The fractal hypothesis is another way to explain this result. We cannot excluded it yet. If this hypothesis is satisfied the expected slope would not be 0.6 and the correction presented here would not be necessary anymore.

The present paper aims at studying what would be the effect of such a partial incompleteness when determining the Hubble constant. The value of the Hubble constant itself will not be discussed here in detail because it is out of the scoop of this paper. We will use the method of "Sosies Galaxies" with the data of our database (LEDA96 Lyon-Meudon Extragalactic Database).

The completeness of the sample will be analyzed in Sect. 2. In Sects. 3 and 4 we will give a way to correct for Malmquist bias in the idealized case of a complete sample working for the determination of the Hubble constant (but not for individual distances) and in the case of a partial incompleteness. In Sect. 5 we will discuss results of previous sections and derive H_o.

2. The sample

2.1. Study of the completeness of the sample

The total number N_T of galaxies with apparent magnitude $B_o < B_{lim}$ is given by the following relation:

$$Log(N_T) = 0.6\ \log(B_{lim}) + K \tag{3}$$

where K is a constant.

This well known relation can be demonstrated easily (see for instance Paturel et al. 1994 for demonstration of a similar relation for apparent diameters). A slope of 0.6 is typical of a complete sample in a homogeneous universe.

In order to check this relation we extracted from LEDA1996 Extragalactic Database all the galaxies with known morphological type, axis ratio, 21-cm line width at 20% and 50% of the peak, apparent B_o magnitude and radial velocity relative to the local group. Our sample is then made of 7230 galaxies. Note that the completeness of the sample must be studied when all required parameters are selected because imposing the knowledge of a given parameter can modify the completeness limit. For instance, assuming the database to be complete up to the apparent magnitude $B = 15.5$ does not mean that the same completeness limit is reached when we impose that the radial velocity is available.

We plotted the diagram $\log N_T$ vs. B-magnitude, and expected to a slope of 0.6. In fact, it is actually different from 0.6 (Fig. 1). Our recent study (Paturel et al. 1994) shows that it is necessary to reject the galaxies of the Local Supercluster to get the correct slope. This is due to the flateness of the Local Supercluster. Thus, by rejecting galaxies with supergalactic latitude $|SGB| < 15$ deg we obtain a slope closer to the expected one (Fig. 2). The sample appears to be complete up to an apparent magnitude of 14.7. However, the curve is composed of two parts: one for magnitudes below 12.0, with a slope of 0.6, like the theory predicts, and the other between the magnitudes 12.0 and 14.7 with a slope of 0.36. It suggests us that a partial incompleteness begins at the magnitude 12.0.

This result shows that it will be necessary to study the effect of the completeness of the sample on the calculation of the Hubble constant when the sample is partially complete.

2.2. Selection of Sosies galaxies

We adopted 16 primary calibrators given by Fouqué et al. (1990) but with some revisions:

- The face-on galaxy M101 was rejected because the 21-cm line width does not give any information on the rotational velocity of the galaxy.
- Some distance moduli have been revised. The distance modulus of M31 has been changed from 24.2 to 24.44 according to Madore and Freedman (1991). The distance modulus of NGC300 has been changed from 26.1 to 26.67 according to Freedman et al. (1992). The distance modulus of M33 has been changed from 24.2 to 24.63 according to Madore and Freedman (1991). The distance modulus of the M101

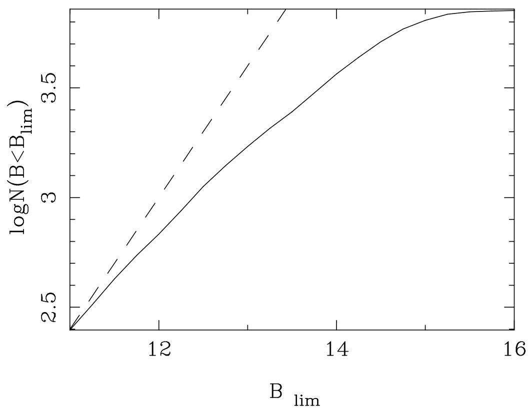

Fig. 1. The completeness curve for the whole sample of 7230 galaxies. The dashed line corresponds to a homogeneously populated 3D-space (i.e. with a slope of 0.6)

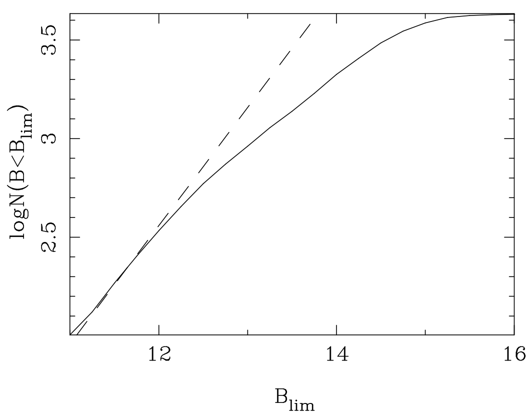

Fig. 2. The completeness curve for sample after the rejection of the Local Super Cluster. A part of the slope becomes in agreement with the expected one but a partial incompleteness still appears between magnitudes 12.0 and 14.7

group (NGC5204, NGC5585 and Homlmberg IV) has been changed from 28.7 to 29.38 according to Madore and Freedman (1991).

Finally, the adopted list is given in Table 1.

From an automatic program we search the "sosies" of these calibrators in our 7230 galaxy sample, with a tolerance of $2-s$ (s being the mean error of the considered parameter). This criterion is rather severe if one considers that we use the mean error of the calibrator itself, because this mean error is generally lower than the one of sosies. Only those galaxies with an apparent magnitude brighter than B_o = 14.5 are kept because it will be shown in forthcoming sections that the correction for Malmquist bias can not be made when the apparent magnitude is too close to the actual magnitude limit. A list of 181 galaxies is extracted in this way (Appendix A).

We calculated the relative Hubble constant, normalized to $100\text{km.s}^{-1}.\text{Mpc}^{-1}$ ($h = H_o/100$), for each galaxy (except galaxies with a radial velocity less than $600\,\text{km}\,\text{s}^{-1}$ that will

Table 1. Primary calibrators: **Column 1:** Calibrator number; **Column 2:** Name; **Column 3:** PGC number (Paturel et al. 1989, 1989a); **Column 4:** Corrected apparent B-magnitude; **Column 5:** Adopted distance modulus (Fouqué et al. 1990 with some revisions explained in the text); **Column 6:** Number of "sosies" galaxies

c	Name	PGC	B_o	μ	n
1	NGC 55	001014	6.79	26.1	0
2	M 31	002557	3.11	24.44	9
3	NGC 247	002758	8.30	26.8	3
4	NGC 253	002789	6.57	27.5	3
5	NGC 300	003238	8.21	26.67	21
6	M 33	005818	5.49	24.63	49
7	NGC 2403	021396	7.91	27.5	41
8	M 81	028630	6.95	27.8	13
9	NGC 3109	029128	8.60	26.0	0
10	IC 2574	030819	9.91	27.8	8
11	NGC 4236	039346	8.82	27.8	6
12	NGC 5204	047368	10.96	29.38	12
13	Holm IV	049448	12.37	29.38	0
14	NGC 5585	051210	10.55	29.38	6
15	NGC 7793	073049	9.06	27.5	10
					181

not be considered in order to reduce the uncertainty due to the dispersion of individual radial velocities).

The relative Hubble constant will be calculated from a logarithmic mean because the distribution of $\log h$ is gaussian unlike the distribution of h. The reason of such a property is that the error on the distance (which is the main contribution to the error on H_o) is a function of the distance itself (i.e. $\Delta r/r = \Delta(\ln r) = \text{cst.}$).

On the other hand, the accuracy strongly depends on the inclination (i.e of axis ratio), magnitude error and 21-cm line width error. The weight of each determination of $\log h$ will be taken as the inverse-square of the individual mean error. This choice is justified in the case of a gaussian distribution. By taking into account only dominant terms, the formal mean error on μ is given by (Bottinelli et al. 1983):

$$\sigma^2(\mu) = \sigma^2(B_o) + 4.75\frac{\sigma^2(W)}{W^2} + 25\frac{q^4}{(1-q^2)^2}\sigma^2(\log R_{25}) \qquad (4)$$

where $q = 1/R_{25}$. The mean error $\sigma(\log h)$ on $\log h$ is then obtained assuming that the uncertainty on the radial velocity is dominated by the random motion, for which we adopted $\sigma(V_c) = 300\text{km.s}^{-1}$. Thus, $\sigma(\log V_c) = 300/(V_c \ln(10))$. The radial velocity which has been adopted in the following is corrected for the Virgo infall, using an infall velocity of 170km.s^{-1} (Sandage and Tammann, 1990). This standard error $\sigma(\log h)$ will be used for the calculation of weighted logarithmic mean.

A raw treatment, from a weighted logarithmic mean of individual relative Hubble constant, would have led to the following result:

$$h = 0.94 \pm 0.03 \qquad (5)$$

This result would be satisfying in absence of Malmquist bias. But now we have to show how to treat the Malmquist bias effect on sosies galaxies when the partial incompleteness is taken into account. This treatment will be voluntarily simplified in order to highlight the main features without entering a difficult statistical treatment.

3. Malmquist bias: treatment in an idealized case

Using a sample made of galaxies brighter than a limited apparent magnitude leads to the existence of a bias: the Malmquist bias. Indeed, the tendency would be to miss the fainter objects and then the mean absolute magnitude would be overestimated. The extragalactic distances become underestimated and H_o overestimated. The reader is referred to Teerikorpi (1984) or Bottinelli et al. (1988) for details.

When the sample is complete, it is possible to have an evaluation of the bias: The mean absolute magnitude $< M_o >$ of galaxies having the same 21-cm line width as a given primary calibrator of absolute magnitude M^{calib} is given by:

$$< M_o > = \frac{\int_{-\infty}^{\infty} M\phi(M)dM}{\int_{-\infty}^{\infty} \phi(M)dM} \quad (6)$$

where $\phi(M)$ is the distribution function of absolute magnitude around M^{calib}. If one assumes that the primary calibrator is well representative of this mean we have $M^{calib} = M_o$.

Now, considering a distance modulus μ and a limited sample with an apparent limiting magnitude B_{lim}, the distribution $\phi(M)$ will be cut at the value $M = B_{lim} - \mu$. Then, for a sample at a true distance modulus μ the absolute magnitude at a given 21-cm line width will be:

$$< M_o >_\mu = \frac{\int_{-\infty}^{B_{lim}-\mu} M\phi(M)dM}{\int_{-\infty}^{B_{lim}-\mu} \phi(M)dM} \quad (7)$$

Similar equation was used first by Kapteyn to derive star group distances (eq. 69 in Kapteyn, 1914).

The corresponding distance modulus is therefore $\mu = B_o - < M_o >_\mu$, i.e.

$$\mu = B_o - \frac{\int_{-\infty}^{B_{lim}-\mu} M\phi(M)dM}{\int_{-\infty}^{B_{lim}-\mu} \phi(M)dM} \quad (8)$$

It should be noted that the distance moduli thus derived are not free from the general Malmquist bias. However, averaged over galaxies at a fixed true (though unknown) distance modulus, Eq. (8) gives the distance modulus corrected from the Malmquist bias of the 2nd kind, i.e. correction for the Malmquist bias at a constant true distance modulus (see Teerikorpi, 1995 for the distinction between 1st and 2nd kinds of Malmquist bias). This latter condition is implicit when one calculates the Hubble constant as an average from $< \log H > = < \log V_c - 0.2\mu(V_c) + 5 >$, *where* V_c *and* $\mu(V_c)$ *are the radial velocity and the derived (from Eq.(8)) distance modulus for a sample galaxy.*

In this relation, we suppose that B_o, B_{lim} and $\phi(M)$ are known. According to Fouqué et al. (1990), we approximate $\phi(M)$ with a gaussian function, with a cosmic dispersion $\sigma = 0.76$:

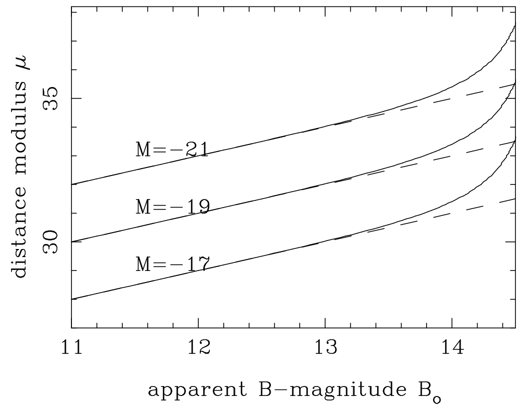

Fig. 3. Curves giving distance modulus when the sample can be considered as complete up to apparent magnitude B = 14.7. The dashed line corresponds to non-corrected modulus

$$\phi(M) = \frac{1}{\sigma\sqrt{2\pi}} \exp - \frac{(M - M^{calib})^2}{2\sigma^2} \quad (9)$$

where M^{calib} is the central value (i.e. the absolute magnitude of the considered calibrators). We will explain in the discussion that the effective cosmic dispersion σ should increase with the number of surveyed galaxies. However, because our aim is not to derive the Hubble constant we will adopt this value.

We are looking for μ that appears in the left member of the equation and in the limits of the integral too. Eq.(8) would be difficult to solve. We prefered to solve it numerically.

The curves corresponding to B_{lim} = 14.7 and $M^{calib} = -21, -19$ and -17 are given in Fig. 3. It is to be noted that, whatever the absolute magnitude, the bias appears always at the same apparent magnitude, but at different distances. The brighter the calibrator, the deeper the unbiased distances. When approaching the limiting magnitude B_{lim} the bias becomes very strong and no correction can be applied. In order to take into account the error on the apparent magnitude B, it would be necessary to convolve the distribution of apparent magnitude with the curve $\mu = f(B)$. In practice, this effect is generally not the dominant one (also because of the weighted mean which gives lower weight to poor magnitudes). Besides, the representation of $\phi(M)$ will include a part of this error. In conclusion, for the sake of simplicity we neglected this effect which would have slightly reduced the final Hubble constant.

Applying Eq.(8) on the sample would have led to a normalized Hubble constant of $h = 0.87 \pm 0.03$. However, it is clear that the completeness is not fulfilled up to an apparent magnitude of 14.7. Hence, let us examine the case of the partial incompleteness, the effect of which is actually the aim of this paper.

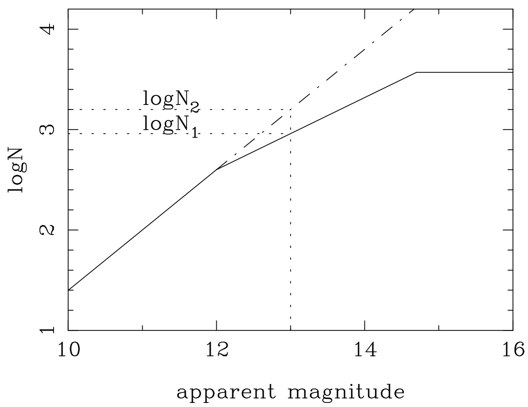

Fig. 4. The completeness curve that we modelize in 3 areas: first with slope of 0.6, the second with slope of 0.36 and the third with slope of 0. At a given apparent magnitude you can get the ratio $\frac{N1}{N2}$ witch represents the probability to obtain a galaxy

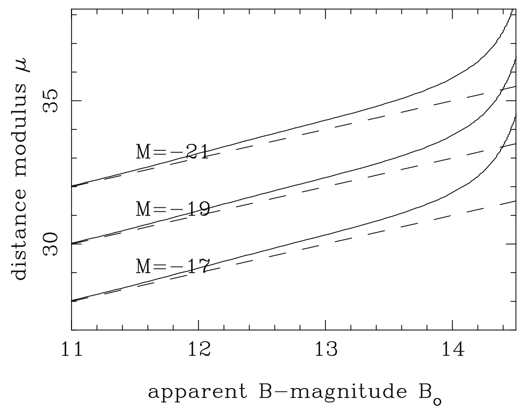

Fig. 5. Curves giving distances modulus corrected with the model of partial incompleteness. The line corresponds to non-corrected modulus

4. Study of the partial incompleteness

The observed completeness curve can roughly be represented with three distinct parts (see Fig. 2 and Fig. 4):

1. Down to B_o = 12.0. The slope values 0.6. All galaxies are accessible. The probability to get a galaxy of given apparent magnitude is $\mathscr{P} = 1$
2. Between the magnitudes 12.0 and 14.7 the slope values 0.36. Not all galaxies are accessible and the probability becomes the ratio $\frac{N1}{N2}$; N1 represents the total number of galaxies in the sample fainter than an apparent limited magnitude and N2 the total number of galaxies corresponding to an homogeneous universe. The probability can be written as $\mathscr{P} = K.10^{(0.36-0.6)B_o}$, where K is a constant giving $\mathscr{P} = 1$ for B_o = 12.
3. After B_o = 14.7 the sample is severely cut and $\mathscr{P} = 0$.

The idea is to use Eq. (8) with a new distribution function $\psi(M)$ containing two pieces of information: the function $\phi(M)$, describing the distribution of the absolute magnitudes at a given 21-cm line width and $\mathscr{P}$, the probability to get a galaxy at a given apparent magnitude. However $\mathscr{P}$ is depending on $B_o = M + \mu$. Then $\mathscr{P}(B_o) = \mathscr{P}(M + \mu)$ and
$\psi(M, \mu) = \phi(M)\mathscr{P}(M + \mu)$. We can then work with the same method than Eq. (8). The relation becomes:

$$\mu = B_o - \frac{\int_{-\infty}^{B_{lim}-\mu} M\psi(M,\mu)dM}{\int_{-\infty}^{B_{lim}-\mu} \psi(M,\mu)dM} \quad (10)$$

The curves corresponding to B_{lim} = 14.7 and M_{calib} = $-21, -19$ and -17 are given in Fig. 5. Note that the bias starts before the magnitude B_{lim} = 12.

From a weighted logarithmic mean we obtain:

$$h = 0.76 \pm 0.02 (n = 181) \quad (11)$$

The Hubble constant has been significantly reduced by more than 15%, just because of the correction for the partial incompleteness (or 23% when comparing with the raw estimate).

5. Discussion and conclusion

The target of this paper was mainly the study of the influence of the partial incompleteness on the Hubble constant. We concluded that the completeness curve (i.e. log N vs. B_{lim}) can be a very usefull tool for correcting Malmquist bias effects, specially in the case of a partial incompleteness. This case is particularly insidious because the completeness is often judged on the last turn-over point of the completeness curve, occasionally far from the beginning of the partial incompleteness. It is our present opinion that Malmquist effect could be corrected in this way for the Hubble constant determination.

As a by-product we may derive a value of the Hubble constant which could be regarded as very secure because the method employed here is not sensitive to any form of the Tully-Fisher relation. However some pending problems remain:

- What is the best description of the distribution of absolute magnitudes at a given rotational velocity?
- Can we improve the accuracy of calibrators?
- Do the large scale motions affect the result too?

Although it was not the purpose of this paper to analyze these problems we made some tests to judge, at least roughly, their influence on the global value of the Hubble constant H_o. Let us analyze each of these items.

(i) Here, we assumed that the distribution of absolute magnitudes at a given rotational velocity ($\log V_M = W_c/2\sin i$) is represented by a Gaussian function with a constant standard deviation (the cosmic dispersion σ). In absence of cut-off (i.e. in absence of bias), an estimation of this standard deviation would not depend on the number of galaxies involved in the Gaussian curve, despite that the actual range of absolute magnitudes will increase with this number (population effect). Due to the cut-off resulting from the limit in apparent magnitude, the *effective* standard deviation of remaining galaxies will change with the population of the Gaussian curve, thus, with the distance, as shown by the Spaenhauer diagram (Sandage, 1994). The calculation would be much more difficult because it would depends on the true galaxy number (not the observed one). This shows

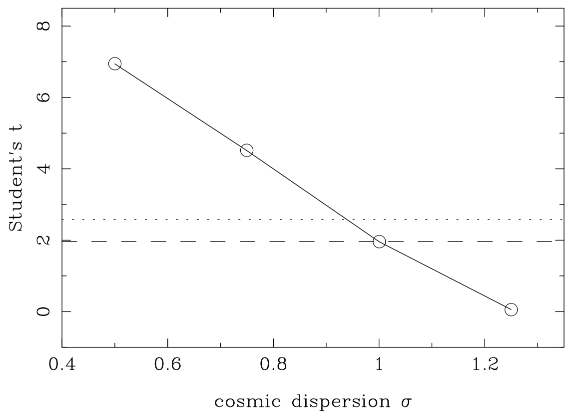

Fig. 6. Student's t (measuring the significance of the slope $\log h$ vs. V_c) plotted as a function of the cosmic dispersion σ. The two horizontal lines correspond to the conventional value t = 2.58 (probability level 0.01) and t = 1.96 (probability level 0.05). From this result, σ has a probability of 0.05 to be less than 1.00 and a probability less than 0.01 to be less than 0.94. We will adopt σ = 1.00.

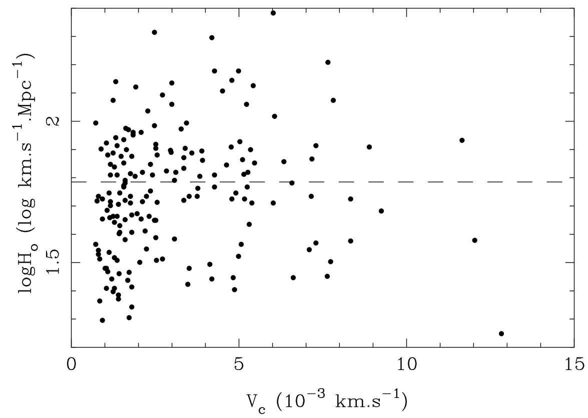

Fig. 7. Log of the Hubble constant vs. the corrected radial velocity (corrected for Virgo infall of the Local Group). The adopted cosmic dispersion is σ = 1.00. The horizontal line represents the upper-limit corresponding to H_o = 61km.s^{-1}.Mpc^{-1}.

that the use of the completeness curve could play a more fundamental role because it allows to estimate this true number.

In order to define the best value for the cosmic dispersion σ, we plotted $\log h$ vs. V_c and estimated the significance of the slope from a Student's t-test. As expected, the adopted value σ = 0.76 is probably too low. The result for different values of σ (0.5, 0.75, 1.00, 1.25 respectively) is shown in Fig. 6. The slope is not significant anymore for $\sigma > 1.00$ (t = 1.96 for the probability level 0.05).

Using a cosmic dispersion σ = 1.00 instead of 0.76 leads to a final Hubble constant of

$$H_o = 61 \pm 2\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \qquad (12)$$

Note that the Hubble constant could be still lower because we have only a lower limit for σ. The plot $\log H_o$ vs. V_c is shown for a cosmic dispersion σ = 1.00 in Fig. 7. In absence of a correction for partial incompleteness, the Hubble constant would have been H_o = 78km s^{-1} Mpc^{-1}. This shows that in this case (σ = 1.00) the correction for partial incompleteness reduces the Hubble constant by more than 20%.

(ii) In order to test the influence of the calibrators we calculated the Hubble constant using only M31 and M33. We obtain: $H_o = 60 \pm 4$km.s^{-1}.Mpc^{-1} (n=58)

(iii) The large scale motion may affect the result. The radial velocity is corrected for the Virgo infall of the Local Group using an infall velocity of 170km.s^{-1} (Sandage and Tammann, 1990) but one cannot exclude that a residual effect subsists. On the Fig. 7 some lower values of $\log H_o$ are visible below V_c = 2000km.s^{-1}.

In 1986, Bottinelli et al. made use of the concept of sosies galaxies to derive the Hubble constant. Their sample was too small to allow an accurate determination of H_o. Nevertheless, they adopted H_o = 75km.s^{-1}.Mpc^{-1}, based on previous distances for primary calibrators. The present revision by about $0.4 mag$ for these calibrators would have given H_o = 63km.s^{-1}.Mpc^{-1}, in good agreement with our result.

In conclusion, the Hubble constant drops about 20% just because of the correction for the partial incompleteness of the sample. From the present result and on the acceptance of the distance modulus of primary calibrators, the value of the Hubble constant would be:

$$H_o \approx 60 \pm 2\,\mathrm{km\,s^{-1}\,Mpc^{-1}} (n = 181) \qquad (13)$$

but the external error is probably much higher.

Acknowledgements. The sample used for this study has been obtained from LEDA lyon-Meudon extragalactic database. We want to express our gratitude to A.M. Garcia who tested some results of this paper. We want also to express our gratitude to P. Teerikorpi who carefully checked the preliminary version and made very useful comments.

Appendix A

On the next two pages.

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Appendix A: the sample of Sosies galaxies Column 1: PGC Name according to LEDA database (Paturel et al. 1989, 1989a); **Column 2**: Alternate name; **Column 3**: Corrected apparent magnitude B_o; **Column 4**: Radial velocity V_c corrected for the Virgo infall of the Local Group; **Column 5**: Class of "sosie" according to Table 1.

PGC	Name	Bo	Vc	c	PGC	Name	Bo	Vc	c
PGC00847	UGC 113	14.01	7747	2	PGC26404	NGC 2848	11.65	1906	6
PGC02071	IC 1555	13.80	1426	5	PGC27430	ESO 565- 2	13.64	2246	15
PGC02215	ESO 242- 1	13.15	3352	7	PGC27473	NGC 2938	13.77	2532	6
PGC03559	UGC 614	13.22	2506	15	PGC27623	ESO 434- 1	13.75	832	10
PGC03611	NGC 338	12.77	4915	2	PGC27796	UGC 5192	13.81	4984	8
PGC03651	UGC 632	14.04	7101	8	PGC27903	IC 2507	12.05	1054	10
PGC03763	NGC 354	13.66	4769	6	PGC27968	UGC 5218	13.94	3059	6
PGC03980	NGC 406	12.02	1248	7	PGC28357	NGC 3021	11.98	1645	7
PGC04784	MCG 3- 4-	13.84	9243	2	PGC29296	NGC 3057	12.79	1786	5
PGC04985	UGC 913	13.77	5283	7	PGC29427	UGC 5451	13.21	792	10
PGC05344	NGC 536	12.22	5338	2	PGC29435	IC 591	13.26	2844	6
PGC05744	UGC 1102	13.65	1976	15	PGC29727	IC 2556	13.18	2305	7
PGC06826	NGC 701	12.01	1764	7	PGC30322	NGC 3206	12.09	1361	15
PGC07066	UGC 1366	13.13	5243	4	PGC30484	UGC 5612	12.02	1254	5
PGC07282	NGC 735	13.19	4778	8	PGC30871	UGC 5676	14.27	1609	12
PGC08393	UGC 1682	13.63	5104	7	PGC30873	NGC 3256	11.94	2490	5
PGC08652	NGC 861	13.64	8337	2	PGC31608	UGC 5784	13.42	6586	4
PGC08954	UGC 1812	13.56	4623	7	PGC31638	ESO 501- 6	13.10	4257	5
PGC08998	IC 223	13.47	1453	12	PGC32351	UGC 5922	13.84	1802	6
PGC09414	NGC 941	12.26	1568	5	PGC32694	NGC 3447	13.33	1110	12
PGC09566	NGC 949	11.64	751	6	PGC32754	NGC 3451	12.56	1425	7
PGC09665	NGC 959	12.10	734	14	PGC33333	UGC 6112	13.13	1080	11
PGC10044	UGC 2140	14.38	4131	10	PGC33940	NGC 3559	12.91	3272	6
PGC11371	UGC 2463	13.77	2046	6	PGC34308	NGC 3589	13.72	2192	14
PGC11836	NGC 1249	11.31	824	7	PGC34508	UGC 6309	13.17	3069	7
PGC12011	ESO 481- 1	12.55	1575	11	PGC35041	NGC 3664	12.62	1367	12
PGC12807	IC 1933	12.13	815	6	PGC35164	NGC 3675	10.38	935	8
PGC13089	ESO 418-	13.35	1010	5	PGC35202	UGC 6446	12.96	849	5
PGC13368	NGC 1385	10.79	1331	6	PGC35347	NGC 3697	12.78	6334	2
PGC13778	ESO 83- 1	14.09	5299	7	PGC35797	NGC 3733	12.04	1394	7
PGC14304	MCG 4-10-	14.28	7297	7	PGC36136	NGC 3782	12.53	919	12
PGC14803	UGC 3004	13.77	3519	6	PGC36238	NGC 3804	13.22	1596	6
PGC16201	ESO 422-	14.30	1268	12	PGC36238	NGC 3804	13.22	1596	15
PGC16764	UGC 3248	13.47	8875	8	PGC37132	NGC 3930	12.65	1068	5
PGC17595	ESO 363- 1	13.40	1049	5	PGC37308	IC 2973	13.74	3341	6
PGC17595	ESO 363- 1	13.40	1049	14	PGC37373	MCG -3-30-	13.67	1713	6
PGC18232	ESO 425-	13.26	1189	6	PGC37525	UGC 6917	12.47	1111	15
PGC18377	ESO 488- 6	12.59	1614	7	PGC37704	UGC 6968	13.95	8346	2
PGC18960	NGC 2146	12.35	1747	7	PGC37735	UGC 6983	12.60	1287	6
PGC19763	UGC 3578	11.89	4524	8	PGC37738	NGC 4025	13.34	3360	6
PGC19931	UGC 3606	14.19	4196	7	PGC39068	NGC 4194	12.30	2724	14
PGC20133	UGC 3644	14.12	3475	7	PGC39252	MCG 5-29-	13.78	7798	6
PGC20429	UGC 3742	13.17	3893	7	PGC39342	IC 3093	14.21	7153	6
PGC20889	IC 2185	14.30	4814	6	PGC39613	IC 776	13.61	2496	6
PGC21120	UGC 3876	13.37	917	6	PGC40408	CGCG 42- 8	14.05	1735	11
PGC21123	IC 2184	13.45	3839	7	PGC40579	UGC 7516	13.99	5394	7
PGC21535	UGC 3964	13.67	1374	15	PGC40597	NGC 4390	12.88	1144	5
PGC22561	UGC 4169	12.72	1792	7	PGC40811	IC 3365	13.53	2418	12
PGC23852	UGC 4444	13.37	2091	6	PGC41472	NGC 4498	12.02	1577	6
PGC24788	UGC 4614	13.77	7661	5	PGC42020	NGC 4561	12.43	1491	5
PGC24791	NGC 2668	14.18	7636	8	PGC42081	IC 3583	12.79	1177	10
PGC25350	ESO 497-	13.41	1776	15	PGC42081	IC 3583	12.79	1177	12
PGC25376	NGC 2731	13.46	2554	6	PGC42348	IC 3617	13.63	2113	10
PGC25986	UGC 4857	13.62	3742	7	PGC42348	IC 3617	13.63	2113	12
PGC26259	NGC 2835	10.18	722	6	PGC42844	MCG 9-21-	14.13	5157	5

PGC	Name	Bo	Vc	c
PGC42999	NGC 4668	12.70	1616	14
PGC43510	NGC 4723	13.83	1243	12
PGC43972	NGC 4790	11.73	1309	6
PGC44014	UGC 8041	12.61	1357	6
PGC44846	NGC 4904	12.06	1175	6
PGC44858	UGC 8127	13.77	1413	11
PGC45358	NGC 4966	13.31	7174	8
PGC46126	NGC 5042	11.76	1283	7
PGC46386	UGC 8365	13.65	1406	6
PGC46746	NGC 5117	13.36	2533	7
PGC46889	ESO 576- 5	12.61	1897	6
PGC47452	IC 4264	13.62	3383	3
PGC48175	ESO 324- 4	12.45	2372	7
PGC48917	NGC 5303	12.35	1600	6
PGC48989	UGC 8733	13.93	2542	6
PGC49741	UGC 8909	14.34	1878	5
PGC49893	NGC 5410	13.29	3920	7
PGC50312	NGC 5480	12.09	2091	6
PGC50905	IC 4386	11.71	1706	7
PGC51289	ESO 385- 1	13.76	3579	15
PGC51290	ESO 446- 5	13.84	1290	10
PGC51290	ESO 446- 5	13.84	1290	12
PGC51400	UGC 9215	12.45	1429	7
PGC51840	NGC 5648	13.35	5240	6
PGC52424	NGC 5727	13.71	1675	6
PGC52717	ESO 22-	12.34	2484	6
PGC52940	MCG -2-38-	12.57	1852	12
PGC53231	NGC 5774	12.15	1623	5
PGC54095	NGC 5875	12.61	3772	8
PGC54260	UGC 9763	13.98	4850	4
PGC55853	NGC 5984	11.57	1229	3
PGC56111	UGC 10041	13.75	2250	6
PGC56397	UGC 10092	13.57	5412	3
PGC56571	MCG 3-41-	14.40	12834	2
PGC58170	UGC 10387	14.14	5058	7
PGC58827	NGC 6207	11.15	1070	7
PGC58891	NGC 6236	12.41	1562	6
PGC60003	NGC 6339	12.85	2343	7
PGC60122	ESO 102-	12.58	4198	5
PGC61455	UGC 11127	13.87	7309	7
PGC61598	IC 4680	12.65	4278	8
PGC62206	ESO 103- 3	13.87	4269	6
PGC62528	IC 4785	11.86	3451	8
PGC62712	ESO 184-	14.19	3504	11
PGC62807	UGC 11406	12.50	4802	7
PGC62830	IC 4821	12.32	2519	7
PGC64140	ESO 595- 1	12.56	2282	5
PGC64939	NGC 6926	12.26	6013	6
PGC65252	CGCG 447- 1	13.94	6068	5
PGC65299	ESO 285- 4	12.46	2568	7
PGC65832	CGCG 448- 2	13.73	5452	7
PGC66087	UGC 11676	13.43	5043	7
PGC66398	UGC 11707	13.89	1089	6
PGC66983	UGC 11769	14.13	6616	8
PGC67215	NGC 7106	13.07	3098	7
PGC68689	UGC 12009	12.35	1446	6
PGC69681	UGC 12181	13.33	4972	5
PGC70184	IC 5273	11.94	1158	6
PGC70349	UGC 12333	14.16	12026	2
PGC70416	MCG 6-50-	14.06	6014	7
PGC70447	UGC 12351	14.25	1813	10
PGC71204	UGC 12547	14.07	5166	6
PGC71473	NGC 7661	13.31	1800	6
PGC71895	UGC 12707	13.98	2711	6
PGC72131	NGC 7732	13.16	2948	11
PGC72237	NGC 7741	11.11	896	6
PGC72367	NGC 7750	12.70	2975	7
PGC72491	NGC 7757	12.64	2997	5
PGC72491	NGC 7757	12.64	2997	14
PGC72506	UGC 12792	13.72	11658	8
PGC73177	NGC 7800	12.48	1833	15

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