

FUNDAMENTAL PROBLEMS IN METROLOGY

COSMOLOGICAL DISTANCE SCALE.

PART II. "UNEXPECTED" COINCIDENCES

S. F. Levin

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A number of models of the cosmological red shift are compared. The spectra of the galaxies in the Local Volume, which define the zero-point of the cosmological distance scale, are found to contain a red-violet dipole of shifts which coincides with the orientation of the galactic axis.

Keywords: cosmological distance scale, Friedman–Mattig model, Doppler model, interpolation model, zero-point, red-violet dipole.

In 1967, after compiling a catalog of interacting galaxies and quasars with significantly different red shifts, the greatly experienced astronomer H. C. Arp, once an assistant to Edwin Hubble, suggested that the anomalously large red shifts of quasars do not obey Hubble's law. For example, a quasar with $z = 2.11$ is observed against the background of the galaxy NGC 7319 with $z = 0.0225$ [1]. Arp's hypothesis was confirmed by the well known students of quasars, G. and M. Burbidge. They pointed out that for quasars the Hubble diagram is a function of luminosity and proposed the following model for the red shift of quasars:

$$z = (1 + z_g)(1 + z_r) - 1. \quad (1)$$

Here the gravitational component $z_g \xrightarrow{GM/(rc^2) \ll 1} GM/(rc^2)$ or

$$z_g = [1 - 2GM/(rc^2)]^{-1/2} - 1, \quad (2)$$

where G is the gravitational constant, and M and r are the mass and radius of the quasar [2]. The basis for this was a model of the corresponding Doppler effect,

$$D = (c/H_0)[(z + 1)^2 - 1]/[(z + 1)^2 + 1].$$

The Physical Factor in Cosmological Measurement Problems. The cosmological component of the red shift may correspond to a strict solution of the Mattig equation [3]

$$z_r = q_0(H_0/c)D_L - (q_0 - 1)\left[\sqrt{1 + 2(H_0/c)D_L} - 1\right]. \quad (3)$$

In 1992, Arp pointed out that the red shift z_0 of a quasar is determined by its absolute luminosity \propto (the K -effect) [4], while it has been shown [5] that

$$z_0 = K \cdot 10^{-0.2\mu}, \quad (4)$$

where $K = 2.6 \cdot 10^{-6}$ is the slope of a regression fit constructed from data on the radial velocity of different stars and interacting galaxies.

TABLE 1. Data Used for the Cosmological Distance Scale [7]

Objects	z	m	Sample size	Ref.
Quasars	0.036–2.877	12.80–20.07	201	[6]
Radio galaxies	0.00086–0.46140	6.98–20.11	172	[6]
Brightest galactic clusters	0.004–0.140	12.5–21.0	10	[9]
Galaxies in the Local group	0.0017–0.0026	7.63–18.13	67	[10]

It can be shown that the K -effect in the linear approximation (2) based on the data of Ref. 5 does not differ from the gravitational red shift, which is given in terms of the effective temperature T_e , the photometric distance $D_L = 10^{-5+0.2(m-\mu)}$ [6], and the absolute ∞ and visible m stellar magnitudes of a quasar [7] by

$$z_g = [1 - 2K_g T_e^2 \cdot 10^{-0.2\mu}]^{-1/2} - 1$$

or

$$z_g \cong K_g T_e^2 \cdot 10^{-0.2\mu} \quad \text{with} \quad K_g T_e^2 \cdot 10^{-0.2\mu} \ll 1, \quad (5)$$

where

$$K_g = (G/c^{-2}) \cdot M_S \sqrt{4\pi\sigma/L_S} \cdot 10^{0.2\infty_S} \sim 5.76 \cdot 10^{-13} \text{ K}^{-2};$$

M_S , L_S , and ∞_S are, respectively, the mass, luminosity, and absolute stellar magnitude of the sun; and σ is the Stefan–Boltzmann constant.

Then model (1) takes the form

$$z = [1 - 2K_g T_e^2 D_L 10^{5-0.2m}]^{-1/2} (1 + z_r) - 1$$

or

$$z \cong (1 + K_g T_e^2 D_L 10^{5-0.2m}) (1 + z_r) - 1. \quad (6)$$

Strict solutions of the Mattig equation (3) for $q_0 = \{-1/2; 0; 1/2; 1\}$ have been examined [7] for the cosmological component of the red shift based on data for objects of different morphological types (see the table) with $H_0 = 74.2 \pm 3.6 \text{ km/sec/Mpc}$ [8] and using the interpolation model

$$z = (H_0/c)D[1 - (H_0/c)D]^{-1}. \quad (7)$$

The limit $z < 0.0017$ ($cz < 500 \text{ km/sec}$) is related to the methods of determining distances in the Local Volume (based on the Cepheids, red giants and supernovae, the Talley–Fisher and Faber–Jackson methods) and the upper bound is related to the Gunn–Peterson effect. The criterion for structural-parametric identification was taken to be a minimum of the average modulus of the inadequacy error of the model for the cosmological component of the red shift, d_z .

Including the gravitational correction (5) has led the Hubble diagram to a scale of photometric distances and “zeroed out” the spread in the red shift relative to the cosmological component, which indicates directly that it is isotropic. Here the most accurate models were the Friedman–Mattig model (3) with $q_0 = 1$ and the interpolation model (7).

However, the closeness of the average modulus of the inadequacy error for the models to the “computer zero” for the 15-bit computer required a refinement in the criterion for structural-parametric identification over the set of properties of the models, naturally, without artificially increasing the number of parameters. Using computer systems with a larger bit range

has extended the circle of competing models with a reduction in the average modulus of the inadequacy error to a level of $d_z \sim 10^{-16}$ [11]. A comparison of the Friedman–Mattig (3), Doppler, and interpolation (7) models has shown the following:

1. In model (7) with $c = 299792.458$ km/sec, the discontinuity point corresponds to a distance $R_0 = c/H_0 = = 13.16_{-0.61}^{+0.67}$ billion light years, while the age of the universe is given by $T_{\text{WMAP-9}} = (13.74 \pm 0.11)$ and $T_{\text{Planck}} = (13.796 \pm 0.058)$ billion years. For an estimate of $H_{0\text{WMAP-9}} = (70.0 \pm 2.2)$ km/sec/Mpc, $R_{0\text{WMAP-9}} = 13.953_{-0.425}^{+0.452}$ and for an estimate of $H_{0\text{Planck}} = (67.9 \pm 1.5)$ km/sec/Mpc, $R_{0\text{Planck}} = 14.385_{-0.311}^{+0.325}$ billion light years. In model (3) with $q_0 = 1$, the parameter H_0/c has the functional significance of a slope and there are no limits on the increase in the radial velocity cz . For $q_0 < 1$, the solutions go beyond the Hubble radius $R_0 = c/H_0$, and for $q_0 < 0$, Eq. (3) had no real roots for the quasars 5C 02.56 and QS 11.08+285. In the Doppler model and the model of Eq. (7), the Hubble radius is a natural limit.

2. The cosmological distance scale based on model (7) changes the estimates of the absolute luminosities and of the distances to objects. This weakens the limit on the red shift for the Λ CDM model because the cosmological age does not match the time for formation of inhomogeneities in the form of galactic superclusters, quasars, and giant voids.

3. With Doppler interpolation of the cosmological red shift, the velocity v_{eq} and acceleration w_{eq} of the expansion of the universe equivalent to the Doppler effect in model (7) are:

$$v_{\text{eq}} = c \frac{D_L / R_0 - 0.5 D_L^2 / R_0^2}{1 - D_L / R_0 + 0.5 D_L^2 / R_0^2};$$

$$w_{\text{eq}} = \frac{dv_{\text{eq}}}{dD_L} = cH_0 \frac{1 - D_L / R_0}{(1 - D_L / R_0 + 0.5 D_L^2 / R_0^2)^2},$$

where the acceleration from the initial value $w_{\text{eq}}(0) = cH_0 = 7.21 \cdot 10^{-10}$ m/sec² increases to a maximum $w_{\text{eq max}} = 9.59 \cdot 10^{-10}$ m/sec² for $z_r = 0.732$ and $D_L = 5.43 \cdot 10^9$ light years, and then falls to $w(R_0) = 0$ without changing sign. This agrees with the estimate of Ref. 12, according to which the transition between slowing-down and accelerating expansion of the universe took place at $z = 0.73$ or 5.4 billion years ago. The position of $w_{\text{eq max}}$ in model (7) does not depend on the proper component of the red shift of objects. In the Doppler model and model (3), there is no analogous nonzero initial acceleration.

4. In a number of papers, the Pioneer anomaly and the cosmological red shift are treated as effects of the same nature. In terms of absolute magnitude, the “acceleration in the expansion” at the zero point $w(0)$ and the estimated “anomalous acceleration” of the Pioneer spacecraft $(8.74 \pm 1.33) \cdot 10^{-10}$ m/sec² (the data on this have been analyzed assuming that it is constant) are close. A subsequent analysis of data for twice the time interval showed that the hypothesis of a linear or exponential variation in the acceleration yields a result that is 10% more accurate [13]. The estimate of the anomalous component of the acceleration of Pioneer-10 in its 23rd year of flight has been reduced to the initial value $w(0) = cH_0 = 7.21 \cdot 10^{-10}$ m/sec² estimated before for model (7), with a tendency to increase further. However, the problem is that the “anomalous component” of the Doppler shift in the Pioneer anomaly corresponds to a violet, rather than a red, shift.

5. The interpolation model (7) and Hubble’s law contain one parameter H_0/c , while model (3) also contains the slowing-down parameter q_0 . In the theory of measurement problems for different accuracy characteristics, simpler models are preferred. Thus, in the linear approximation for the proper component, the photometric distance scale, which combines the Hubble diagram and law for the red shift z and the stellar magnitudes m over an interval of 0.21–9.16 billion light years, acquired the isotropic form [7]:

$$D_L = z[(1 + z)(H_0/c) + K \cdot 10^{5-0.2m}]^{-1}.$$

The strict equation (1) with model (6) reduces to the equation

$$(1 - D_L / R_0) \sqrt{1 - 2K_g T_e^2 D_L 10^{5-0.2m}} = 1/(1 + z), \quad (8)$$

which has an analytic solution, but in this case it is more conveniently solved numerically. The solution of system of equations (8) for a sample of 201 quasars with the standard effective temperature of quasars on the order 30000 K yields a scale on which

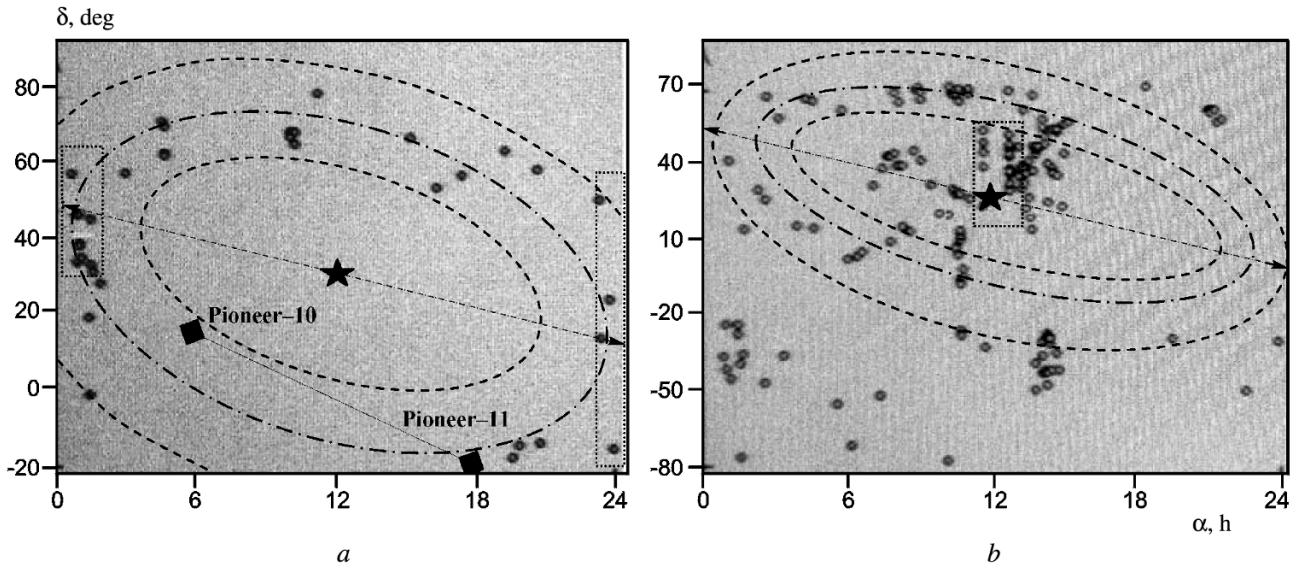


Fig. 1. The distribution over the celestial sphere in equatorial coordinates of the galaxies in the Local Volume with violet (*a*) and red (*b*) shifts. The star denotes the position of the apex of the sun's motion relative to the microwave background. The rectangular regions indicated by the dotted lines denote a sample along the "dipole" axis.

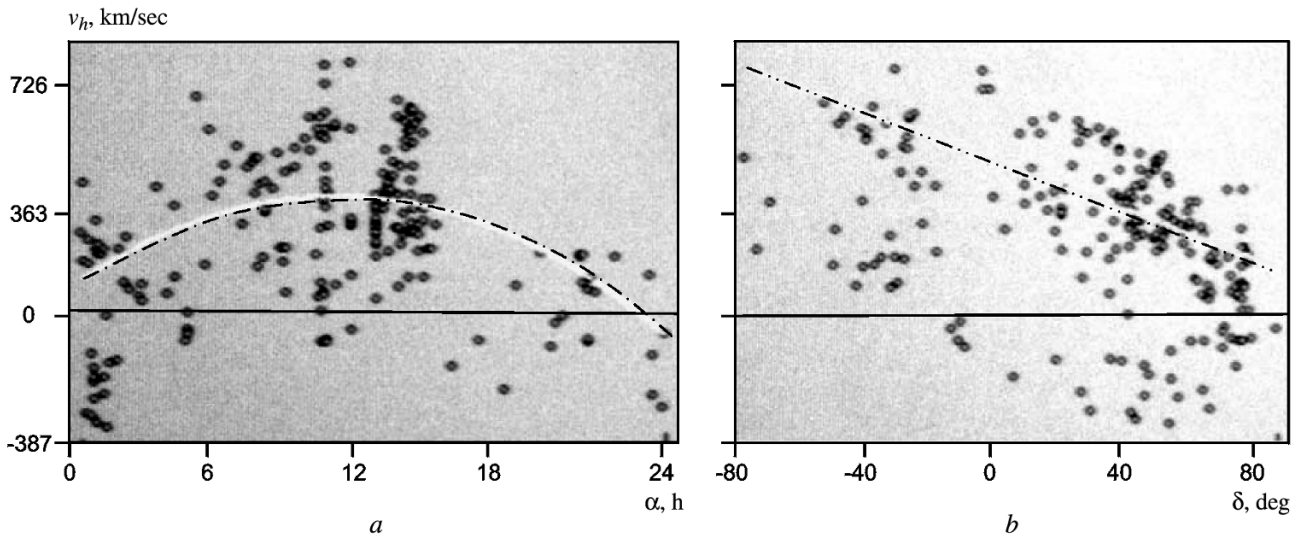


Fig. 2. The distribution of the radial velocities of galaxies in the Local Volume in equatorial coordinates with respect to the right ascension (*a*) and declination (*b*).

the most distant quasar lies at a distance of 90 Mpc [6]. This means that the standard effective temperature of quasars is inconsistent with their visible stellar magnitude or that Arp's hypothesis that the red shift of quasars is not entirely cosmological is implausible. It is more likely that the dipole anisotropy of the observed red shift and the microwave background emission are associated with large-scale inhomogeneities in the proper (gravitational) component (2), the dipole of which is close to the polar axis of the galaxy.

The Zero Point of the Cosmological Distance Scale. In 1971, A. Sandage pointed out that the Hubble constant depends neither on the direction to a galaxy nor on the averaging interval, i.e., both within and beyond the confines of the

cells of homogeneity in the structure of the universe of size on the order of 300 Mpc, and the “uniform Hubble flux” is observed at a distance of 1.5–2.0 Mpc [14]. However, there is a violet component in this flux in the northern equatorial hemisphere – 37 galaxies of the Local Volume in the form of a belt in Andromeda, Camelopardalis, Ursa Minor, Draco, and Pegasus [10]. The belt extends like a “horseshoe” between the points of intersection of the ecliptic and the galactic equator with a center at the boundary of Virgo and Leo (Fig. 1a), while the 167 galaxies in the Local Volume with a red shift are grouped more uniformly toward the northern galactic pole in Canes Venatici, Coma, Virgo, and Centaurus (Fig. 1b).

An analysis of the distribution of the radial velocities V_h of these galaxies using the MMK–STAT M program [15] revealed the presence of a systematic component with respect to the declination δ , the right ascension α , visible stellar magnitude m , and photometric distance D_L (Fig. 2):

$$V_h = \begin{cases} 129.28175 - 2.9535704\delta + 5.8127337m + 30.177181D_L, & V_h > 0; \\ -18139638 + 2.1469548\alpha - 7.1032076m + 45.310307D_L, & V_h < 0. \end{cases}$$

In other words, in the Local Volume there is a red-violet dipole oriented toward the temperature maximum of the microwave background radiation, the apex of the sun’s motion relative to it, and the dipole of the anisotropy in the red shift [16].

The separation from the Local Volume of the galaxies on the axis of the red-violet dipole with respect to the nodes of the ecliptic within an interval of 4.09–19.00 Mpc with structural changes in an interval from –0.62 to +3.92 Mpc yields the following compositional MMKMNK estimate [15] for the characteristic positions of the Hubble law: $\bar{V}_h = -264.5$ km/sec within an interval of –0.91 to –0.62 Mpc and $\bar{V}_h = 346.0$ km/sec outside it. Combining the galaxies with violet and red shifts in the interval from –2.3 to +10.4 Mpc gives 90% tolerance limits of

$$\tilde{V}_h = -151.761 + 72.846D \pm 193.876 \text{ km/sec}$$

with a slope of 72.846 km/sec/Mpc and a zero point of $V_h(0) = -151.761$ km/sec.

The nonzero heliocentric velocity at the zero point is related to the fact that the gravitational shift in the spectra of the members of the Local Volume could be neglected since most of them are dwarf and irregular galaxies. And this conclusion could hold for the other objects, because extending model (1) to the peculiar Doppler effect would mean that of the 167 objects in the Local Volume with a red shift, only 9 would remain.

In 1959, Volders showed that the rotation curve of the spiral galaxy M33 does not correspond to newtonian dynamics for the observed distribution of matter [17]. In the 1970s, this result was extended to many other spiral galaxies, where it was assumed that there may be large amounts of invisible matter at large distances from their centers [18]. And in 1983, Arp found that in the M31 and M81 galactic groups in the Local Volume the red shift of the central spiral galaxies is systematically lower than for the accompanying dwarf galaxies [19]. The picture is the same in the Galaxy–Magellanic clouds system. In 1986, Sandage [20] noted an increase in the local Hubble constant at distances of 1–2 Mpc and assumed that this is a consequence of a deceleration of the Hubble flux by the attractive force of the Local group. In 1988, Tully discovered a peak in the local Hubble constant of up to 90 km/sec/Mpc at a range of 7–30 Mpc [21], and in 1997 Karachentsev and Makarov discovered a similar peak in the Hubble constant $H_0(2 \text{ Mpc}) \sim 90$ km/sec/Mpc [10]. Here the mean square deviation in the peculiar velocities in the Local Volume is almost the same for giant and dwarf galaxies at 72 ± 2 km/sec with a variation of no more than 3%.

These peaks are indicative of a distribution of “dark matter” around spiral galaxies that appears to be related to Arp’s discovery in the galactic groups M31 and M81. A test based on the later data [10] confirmed this discovery, of which many cosmologists had been skeptical previously.

Thus, the violet shift in the near zone of the Local Volume (an extension of the red shift) and the excess red shifts in galactic groups are related to gravitational anomalies of “dark matter,” while the “uniform Hubble flux” begins much earlier than Sandage noted.

Pioneer-11 is moving toward the center of the galaxy and Pioneer-10 is moving in the opposite direction; these directions are close to the points of intersection of the ecliptic and the galactic equator, i.e., they are in the region of a violet shift,

rather than a red shift, and are simultaneously in a “plane of dark matter.” This may explain the difference in the anomalous components of these spacecraft. This component is larger for Pioneer-11, which is moving away from the galactic center.

Conclusions. A cosmological distance scale has been constructed in which accounting for the observed stellar magnitudes and a correction for the gravitational red shift in the spectra of extragalactic sources has made it possible to reduce the spread in the estimates in a fundamental way and to combine extragalactic objects of different morphological types into a common isotropic dependence.

This purely metrological interpretation of measurement data at the boundary of the “computer zero” has shifted the criterion for the choice of models of the red shift toward a description of the effects without artificial parameterization and a direct fit to the measurement data. The list of “unexpected results” [22] has been supplemented with some “unexpected coincidences”:

1) of the apex of the sun’s motion, of the anisotropy dipoles of the microwave background, of the slowing-down parameter and red shift of extragalactic objects, and of the violet shift of galaxies with the galactic polar axis, with the largest structural element of the observed part of the universe in a northerly direction, and with the system of giant voids to the south;

2) of an equivalent to the Doppler effect in the acceleration of the “expanding universe” in the interpolation model for the cosmological red shift with a second order discontinuity at the maximum, with the epoch of the “beginning of accelerated expansion of the universe,” and with a minimum in the absolute magnitude of the “anomalous acceleration” of the Pioneer spacecraft, but for a violet shift;

3) of a significant part of the red shift of quasars with a gravitational effect;

4) of the result of introducing a correction for the proper red shift of quasars in their observed red shift with the hypothesis of an isotropic cosmological component owing to compensation of the statistical spread for the cosmological component; and

5) of the interpolation model with a primitive model of expansion with constant velocities when slowing down and the limit on the radius of gravitational effect are taken into account.

Hypotheses regarding the nature of the cosmological red shift were advanced a long time ago by P. A. M. Dirac, who assumed that it was a consequence of a change in the gravitational constant or “ageing” of photons as they lose energy in overcoming the resistance of the medium. G. and M. Burbidge have treated the red shift as a Doppler effect and a gravitational effect. Alternative hypotheses for the causes of the red shift, besides the “standard expansion of the universe,” have included viscosity of the ether, spontaneous radio luminescence of hydrogen atoms, vacuum fluctuations, and loss of kinetic energy with conversion into the energy of vacuum fluctuations, and many others.

The simplest hypothesis, however, is “dark damping” corresponding to the distance propagated by radiation from its source.

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