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HIGH REDSHIFT 21-CM LINES

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On résume l'ensemble des décalages vers le rouge dont on dispose à partir de la raie 21 cm. La plus grande valeur obtenue pour la raie HI en émission est z =0.0369, et z = 0.692 en absorption. Il y a un excellent accord avec les décalages vers le rouge mesurés optiquement (lorsqu'ils existent). Les deux techniques donnent la même valeur (en moyenne), et montrent que les décalages vers le rouge sont indépendants des longueurs d'onde dans un intervalle de longueur d'onde de $\sim 5 \times 10^5$, et un intervalle en z de -0.0012 à +0.692. C'est une condition nécessaire, mais non suffisante pour interpréter les décalages vers le rouge par l'effet Doppler. Des limites sont fixées pour la variation possible de certaines constantes atomiques fondamentales en fonction de z, et si z est une mesure de la loi d'expansion de Hubble, en fonction du temps, jusqu'à des temps au moins égaux à 35% de l'âge de l'Univers.

The 21-cm spectral line of neutral hydrogen has been detected in emission in extragalactic sources over a redshift range of z ($= \Delta\lambda/\lambda_o = \Delta\nu/\nu$) of -0.0012 to +0.0369; corresponding values of cz are -350 to

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+11,060 km s^{-1}. The low (negative) redshift value is fixed by the random motions of nearby galaxies. The upper limit is dependent upon the observational signal-to-noise ratio; this limit is continually being extended. Measurements of the 21-cm line in absorption are in the range z = 0.0008 to 0.692. Here the restrictive limitations of the inverse-square law do not apply and the detection of even larger values of z_{21} can be expected in the future.

A comparison of redshifts measured at optical wavelengths and at 21-cm yields: (1) A verification of both measurement techniques. (2) A test of the wavelength invariance of the redshift. And (3) limits on the constancy, with z, of certain fundamental constants. The vast majority of 21-cm redshifts are for HI in emission. Over 500 values are published with optically measured redshifts available for ~60% of these. Summaries and comparisons of various subsets of these data have been discussed previously, e.g.: Roberts (1972), Lewis (1975), and Bottinelli and Gouguenheim (1976).

The most recent compilation of such data is by Rubin et al. (1976). This sample extends to the highest emission redshift currently available and is also the most homogeneous in that both the optical and radio data were obtained by the same group yielding internally consistent error estimates. Their data, for 120 galaxies, are summarized in Figs. 1 and 2. The sample are ScI-ScII galaxies in the magnitude $14 \leq m_{Zwicky} \leq 15$. Figure 1 is a histogram of the differences 21 cm minus optical values of $c\Delta\lambda/\lambda_o$. The weighted mean of these differences is 4 ± 4 (standard deviation of mean) km s^{-1}. There is clearly excellent agreement between both sets of measurements with either technique capable of yielding relatively high precision. We also note that z_{opt} and z_{21} (emission) refer to different regions of a galaxy. The optical data are generally for the nuclear region while the 21-cm data are based on the midpoint of the global velocity profile, i.e., for the distribution of neutral hydrogen throughout the entire system. An anomalous redshift difference between

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the nuclear region and the rest of the galaxy is not indicated in any of the samples tested.

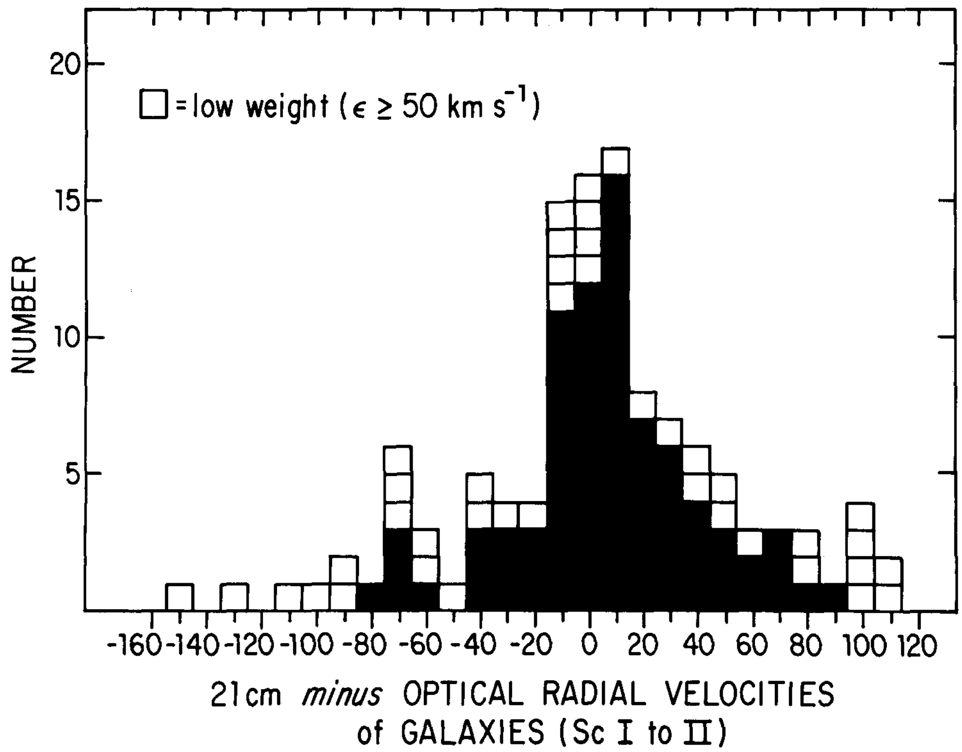

Fig. 1 - Histogram of 21 cm minus optical values of $c\Delta\lambda/\lambda_o$. This sample of 120 intrinsically bright, late-type spirals is from Rubin et al. (1976).

Figure 2 is a plot of cz_{opt} vs cz_{21}. The two regression lines have the weighted solution $cz_{21} = -4.2\ (\pm 13.1) + 1.002\ (\pm 0.002)\ cz_{opt}$, and $cz_{opt} = 7.6\ (\pm 13.1) + 0.998\ (\pm 0.002)\ cz_{21}$. To within the errors of the solution we find a zero intercept and slope of one. Other galaxy samples give similar results (see, e.g., Roberts 1972).

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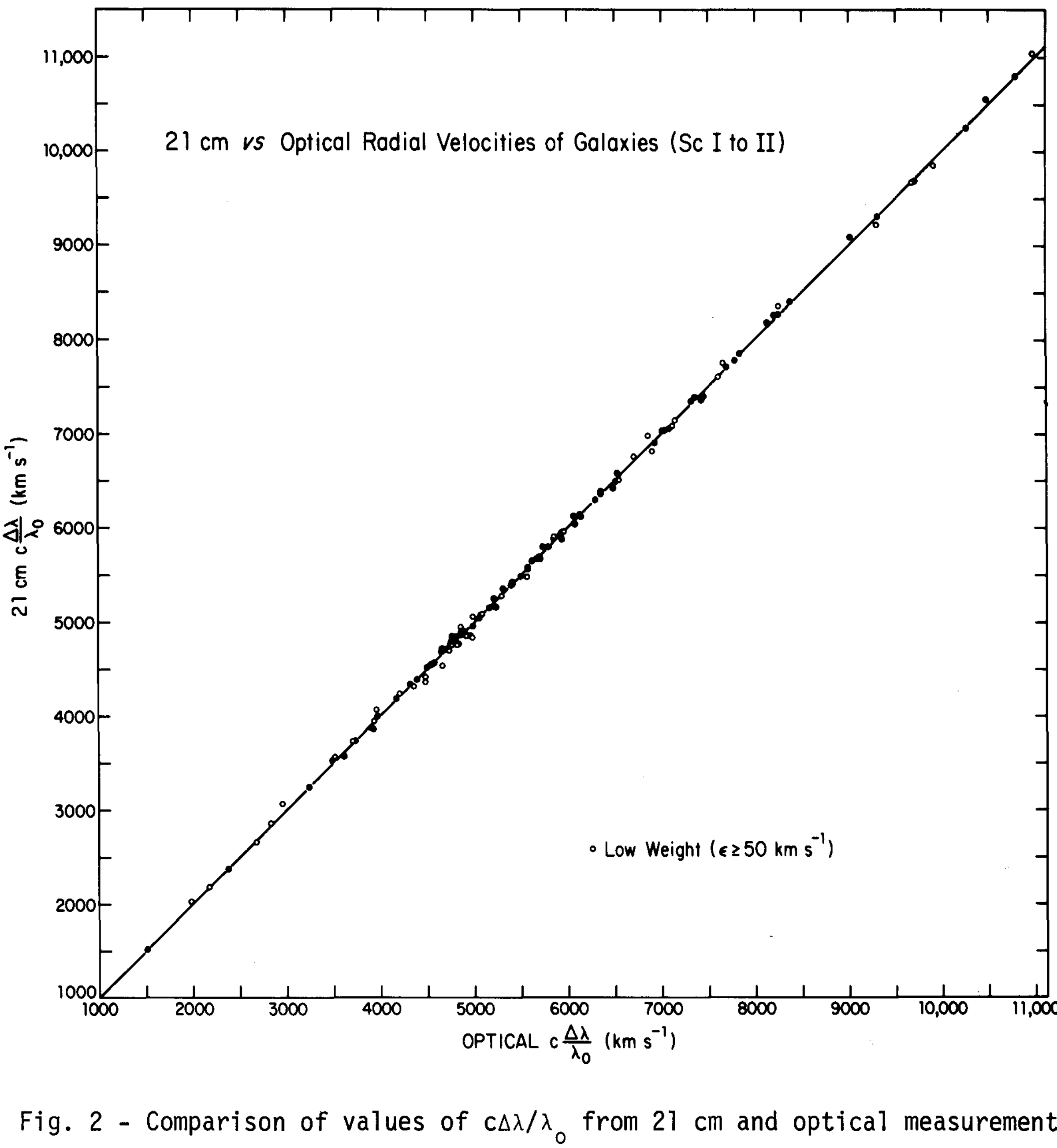

Fig. 2 - Comparison of values of $c\Delta\lambda/\lambda_o$ from 21 cm and optical measurements of 120 spiral galaxies (Rubin et al. 1976).

The data of Figs. 1 and 2 as well as previous studies also establish the wavelength invariance of the redshift; an invariance over a wavelength range of $\sim 5 \times 10^5$ and for HI in emission to $z = 0.0369$. This test is a necessary, but not sufficient condition for the Doppler interpretation of redshifts, e.g., gravitational redshifts are also wavelength invariant. Any other explanation of redshifts must satisfy this condition.

Large z_{21} values (>0.5) are available from two absorption measurements: 0.692154±0.000002 for 3C286 (Brown and Roberts 1973) and 0.52385±0.00001 for AO 0235+164 (Roberts et al. 1976). For 3C286 no optical redshift at z_{21} was initially known, only an optical emission z at 0.849. This is a common occurrence in quasar spectra where usually $z_{em} > z_{abs}$. More recent optical studies (Spinrad, private communication) show weak absorption lines at essentially the identical redshift measured at 21 cm. The BL-Lac type object AO 0235+164 shows two sets of absorption redshifts, $z = 0.540 \pm 0.0001$ and $z = 0.851 \pm 0.001$ (Burbidge et al. 1976; Rieke et al. 1976). A redshifted 21-cm measurement at the lower value yields a clear, unambiguous absorption line, or rather lines, since there is structure in the absorption feature, see Fig. 3 (Roberts et al. 1976). The midpoint of this absorption feature yields $z_{21} = 0.52385 \pm 0.00001$ (heliocentric); the optical value adjusted to a heliocentric reference frame is 0.52392±0.00010 and the differences z_{21} minus z_{opt} is -0.00007±0.00010. To within the errors of measurement the redshifts determined from optical lines and from the 21-cm line are identical. A 21-cm search for the high redshift system in AO 0235+164 as well as studies of other BL-Lac objects are, at present, inconclusive. All that can be said is that the HI optical depth for these cases is less than in the $z \sim 0.5$ system of AO 0235+164.

With the values of z derived from the MgII fine structure and the HI hyperfine absorption lines seen towards AO 0235+164, we can place limits on the variability, with z, of 3 products of the fine structure constant, α, the nuclear g-factor of the proton, g_p, and the ratio of electron to proton mass, $\left(\frac{m}{M}\right)$, viz., $\alpha^2 g_p \left(\frac{m}{M}\right)$, $g_p \left(\frac{m}{M}\right)$, and α. Further, if we adopt z as a measure of the Hubble expansion, then we obtain limits on the variation with time of these quantities over at least 35 percent of the age of the universe.

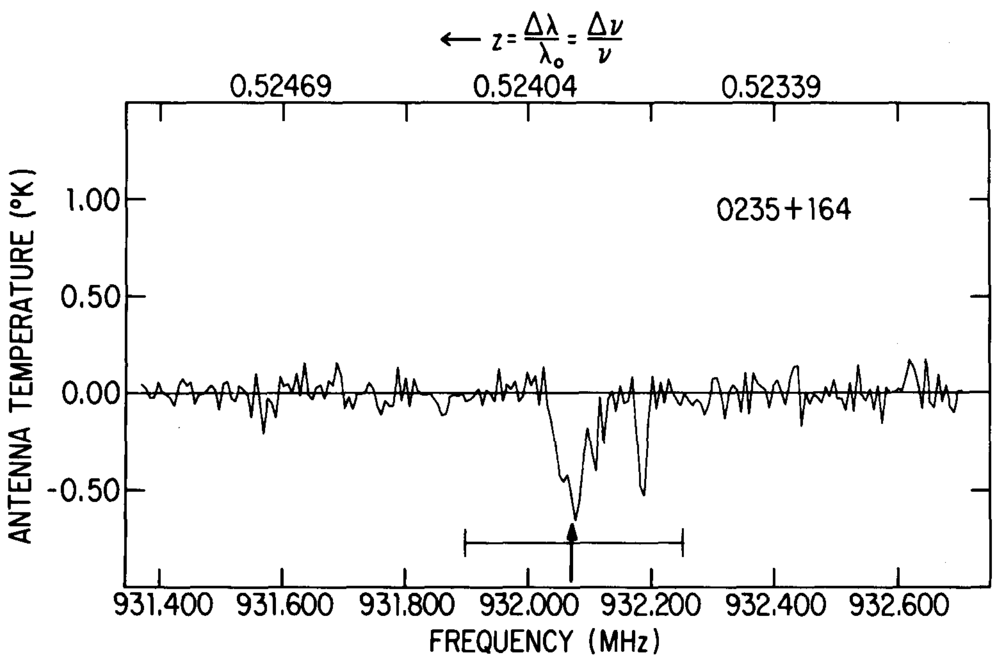

Fig. 3 - The 21-cm absorption profile measured towards the BL Lac object AO 0235+164. The midpoint of the entire absorption feature is used to define z_{21}. The optically derived value of z and its associated error are indicated by the arrow and error bars (Burbidge et al. 1976).

The tests involve (i) A comparison of the HI hyperfine frequency with the frequency of a resonance line for an alkali-like atom (Mg^+) at two epochs (or z's), the radio source absorption and laboratory. This

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yields a limit on the variation for the product $\alpha^2\, g_p \left(\frac{m}{M}\right)$. (ii) A comparison of the HI hyperfine frequency and the Mg^+ fine structure separation. From this we obtain a limit on the constancy of the product: $g_p \left(\frac{m}{M}\right)$. And (iii) from the optical data alone, specifically the observed separation of the Mg^+ fine structure doublet, we obtain information on the constancy of α. This last test has been made previously from astronomical data (Bahcall, et al. 1967). The details of these tests are given by Wolfe, Brown and Roberts (1976); their results are: From (i) $[(\alpha^2 g_p\ m/M)]_z = [(\alpha^2 g_p\ m/M)]_{lab}\ [1.00005\pm0.0001]$, i.e., the product of these three quantities has not varied by more than one part in 10^4 from $z \simeq 0.5$ to $z = 0$. No assumption regarding the interpretation of z has been made in arriving at this value and hence any theory which invokes changing these atomic constants to explain large z's is confined to this limit. If we adopt z wholly as a measure of the Hubble expansion then for a Friedmann cosmology with deceleration parameter $q_o = 0$, the look-back time is $\geq 0.7\times10^{10}\ (50/H_o)$ years and we obtain $|d[\ln(\alpha^2 g_p\ m/M)]/dt| \leq 2\times10^{-14}\ y^{-1}$. This is the lowest limit presently available on the variation of atomic quantities and involves such fundamental parameters as the quantum electrodynamical coupling constant (α) and an expression of the internal structure of the proton (g_p).

From (ii) we obtain $|d(\ln g_p\ m/M)/dt| \leq 8\times10^{-12}\ y^{-1}$ and from (iii) $|d(\ln \alpha)/dt| \leq 4\times10^{-12}\ y^{-1}$. All of these limiting values are determined wholly by the uncertainties in the measurements of the optical spectra of AO 0235+164. Higher dispersion and greater accuracy on measured z_{opt} for individual spectral lines will improve these limits.

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DISCUSSION

W.G. TIFFT: Could Roberts or Rubin comment on the comparison of optical and radio redshifts in the 6000 - 7000 kms^{-1} range where Simkin argues night sky effects might be serious for optical redshifts.

M.S. ROBERTS: Simkin's analysis is for absorption lines while most of our data are based on optical emission lines (Hα and [NII]). It would be interesting to observe some of our ScI galaxies in this velocity range in the blue and at a dispersion similar to that used by Simkin in her analysis to check velocities from the H and K lines vs our 21-cm velocities. A list of our galaxies is given in the Sept. 1976 issue of the Astronomical Journal.

V. RUBIN: Of about 200 spectra for our ScI galaxies, 85 % of the plates are centered at Hα, so the optical velocities come from emission lines. Hence the discussion of Simkin is not relevant. About 30 spectra are centered in the blue, and velocities come from H and K absorption and 3727 [O II] emission, when present. The dispersion for these blue plates is at least 2 x that mentioned by Simkin. I feel quite secure that errors as large as 1000 kms^{-1} are not present.

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