Colloque de l'Union Astronomique Internationale
N° 37 – DECALAGES VERS LE ROUGE ET EXPANSION DE L'UNIVERS

SPECTROSCOPY AND THE HUBBLE DIAGRAM OF FAINT RADIO GALAXIES

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RÉSUMÉ

L'ÉTUDE SPECTRALE ET LE DIAGRAMME DE HUBBLE DES RADIOGALAXIES

Nous discutons les identifications récentes et les observations des radiogalaxies faibles, au décalage spectrale z = 0.75, en les présentant dans des diagrammes Hubble.

Les corrections incertaines de la magnitude apparente et la correction sans doute grande pour l'évolution galactique, empêchent une détermination directe du modèle cosmologique. Nous présentons aussi de nouvelles données au sujet de l'évolution temporelle de la couleur et de la luminosité d'une galaxie. Les galaxies éloignées apparaissent plus lumineuses et plus bleues que les galaxies elliptiques proches, en accord approximatif avec les prédictions des nouveaux modèles.

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* Visiting astronomers at Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

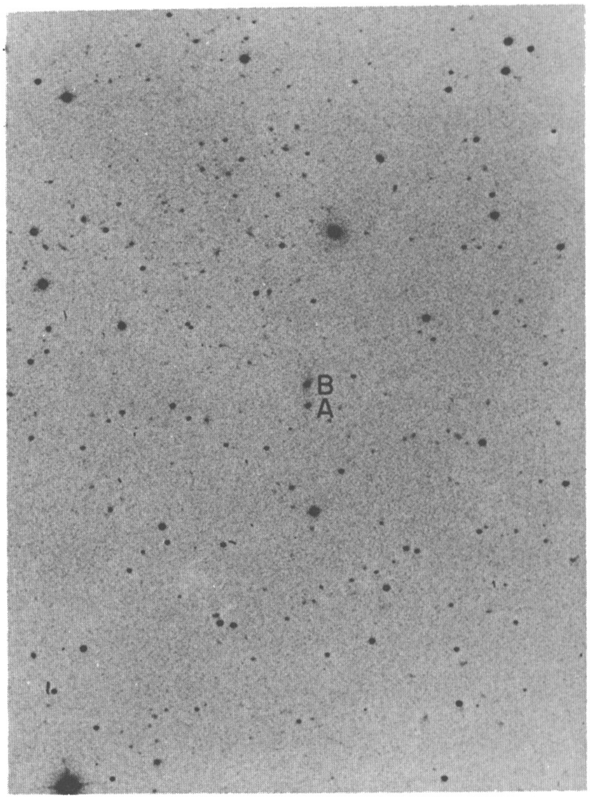

Fig. 1

3C 326

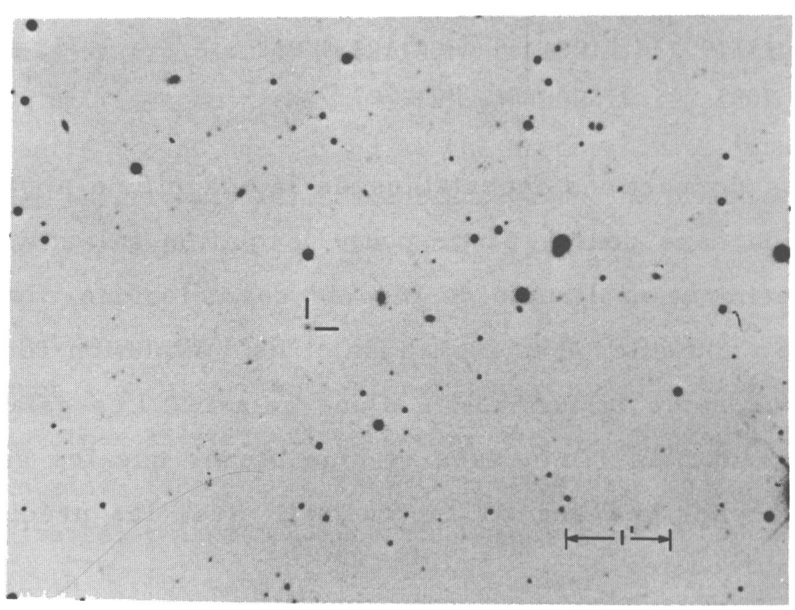

Fig. 2

3C 343.1

Figure 1.: Print of a direct photograph (Crossley, 0.9 m reflector) of the pair of E galaxies associated with the giant radio source 3C 326. These galaxies are near V = 16 and have a mean redshift z = 0.088.

Figure 2.: Print of a deep direct plate, red region, of the faint ($V \sim 21$) radio galaxy 3C 343.1. The original photograph was obtained with the Kitt Peak 4-m reflector, with a 127-04 (GG 495) plate-filter combination. The redshift has recently been measured at z = 0.750.

https://doi.org/10.1017/S0252921100053677 Published online by Cambridge University Press

I. GENERALIZATIONS ON FAINT RADIO GALAXIES

Distant radio galaxies, by virtue of their high luminosity ($\bar{M}_V$ = -23.0 for H_0 = 50) and unique identification possibilities, may be attractive standard candles for a variety of cosmological tests. However many of these hopes seem to be becoming submerged into large corrections for galaxy (stellar and dynamic) evolution, which probably is going to be the direction of considerable faint-galaxy research in the future.

We shall not spend much time on the triumphs of recent radio source mapping and optical identifications. Obviously this has required collaboration between radio and optical astronomers. The new radio maps, mainly generated with the large arrays at Cambridge and Westerbork, have provided some unambiguous new identifications when combined with deep direct photographs (c.f. Smith, Burbidge and Spinrad 1976, Kristian and Sandage 1970, Kristian, Sandage and Katem 1974, and Longair and Gunn 1975). However, problems still do exist; large- and small-scale radio structures, when quite asymmetric, provide a source of identification ambiguity/error. A fair fraction of even 3CR source identifications have been revised in the last few years. We illustrate in Fig. 1 a recently identified pair of moderately bright E galaxies near the midpoint of the giant radio source, 3C 326 (Willis 1976). At one time this source was considered of likely galactic origin, due to its large angular extent.

The spectroscopy of faint radio sources, is very time consuming, even with the new digital devices on large reflectors. Recent work at the Lick, Hale, and Kitt Peak Observatories suggests that sky-subtracting spectroscopic data, with a rather low S/N ratio, may be obtained on almost any object photographable with a large reflector. For example, we show in Fig. 2, the faint radio galaxy 3C 343.1 ($V \sim 21$). This object has the largest redshift so far measured for a radio galaxy, with $z = 0.750$.

Often, but not always, the noisy spectra will yield sufficient information for both a redshift determination and a color synthesis. Those data are the heart of the results we discuss here. An example of the S/N

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obtainable in reasonable times is given in Fig. 3, which shows the sum of 4 spectra of 3C 123.

Can things be improved further? We anticipate some gains from new state-of-the-art detectors, but we recall that this work is most seriously limited by the surface brightness of the night sky, especially at long wavelengths. The permanent airglow OH bands, which are strong at $\lambda > 6850$Å, are the main culprits. Future satellite observers will be in an enviable position in this regard. For comments on the subject see the reviews by Spinrad (1976) and by Smith (1977).

To date five faint normal (not N) radio galaxies with $z > 0.46$ have been spectroscopically observed. There are also a few other uncertain red-shift cases. Also we now have one faint cluster (non-radio) galaxy with a tentative redshift of $z = 0.947$.

So far, magnitudes for these faint galaxies come from two sources; the best data are the Hale (conventional) photoelectric multi-aperture data of Kristian, Sandage and Westphal (1977) [hereafter KSW]. Lick scanner-synthesized magnitudes are the other source of photometry we will use. R. Kron's integral photographic photometry is available for the distant cluster, 1305 + 29, and a few of the radio galaxies have less accurate uncalibrated photographic magnitudes.

II. THE HUBBLE DIAGRAM FOR LARGE-REDSHIFT GALAXIES

We have constructed Hubble diagrams with these separate data, for our large-z sample of (mainly) radio galaxies. Because we are dealing with objects just above the current observational limits, we should not expect our m, z relations to look very tight, and perhaps not be convincingly fit by linear regression lines.

An immediate worry should be possible selection effects which lead us to these very radio galaxies. The possible optical selection effects for the Hubble diagram of radio galaxies are not well defined. One scenario (Smith 1977) suggests a "radio Scott effect", in which radio and optical luminosity are well-correlated. However, the available data on emitted

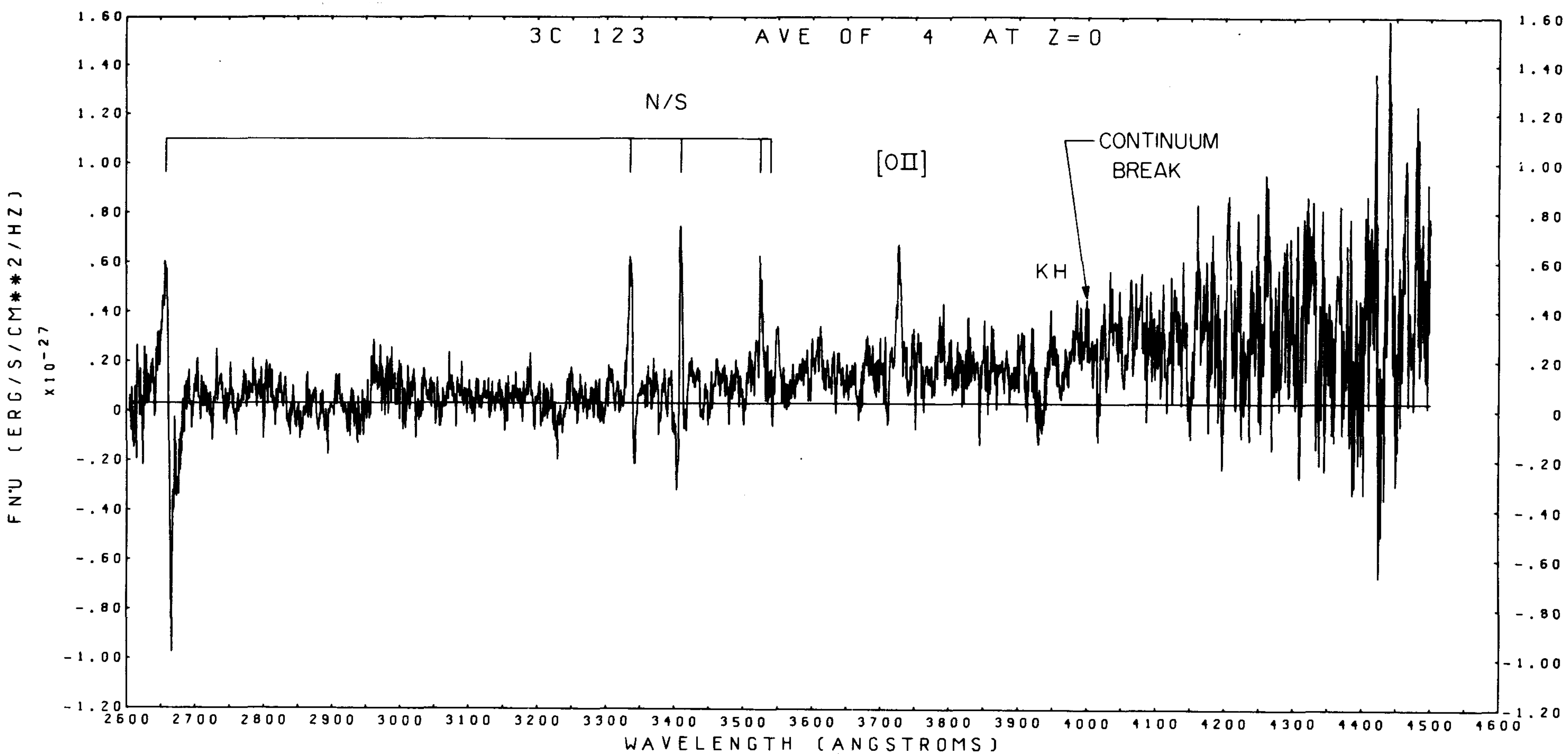

Figure 3.: Lick IDS spectra of 3C 123 (z = 0.637) shifted back into the galaxy's rest frame by computer. Note weak λ3727 emission, the Ca II absorption lines, the λ4000 continuum discontinuity, and the gradual fall off of flux toward the ultraviolet. The spectrum appears flatter than do F stars over λλ3100 - 2600 Å, despite the low S/N ratio. Note that other emission lines are mainly imperfectly subtracted Hg lines at observed wavelengths λλ4358, 5461, 5790. The flux at emitted λ3400Å corresponds to a visual magnitude of 21.7.

radio power and optical galaxy luminosity shows no correlation in the 3CR sample of Smith, Spinrad and Smith (1976) or that of Kristian (1977). Still, in individual cases we are somewhat suspicious. For example, 3C 123 is an extremely powerful radio source associated with a (super-luminous?) large cD galaxy.

A second problem is that of converting raw apparent magnitudes to self-consistent ones which are distance-effect independent.

The operational methods utilized here are slightly different from those of Sandage (1972), Gunn and Oke (1975), and Sandage, Kristian and Westphal (1976). Our magnitude-correction precepts are:

(a) We have employed a power-law form for the aperture correction, following Gunn and Oke. We correct to a projected standard metric diameter, $\theta_m(z)$, with D = 50 kpc, assuming $q_o = 0$. This standard size projects to an angular diameter of 5".1 at z = 0.75. The correction in magnitudes is then:

$$\Delta m(\text{ap.}) = 1^{m}\!.75 \log \frac{A}{\theta_m(z)} \quad ,$$

where A is the entrance diaphragm aperture.

(b) We used Oke's (1971) K-corrections out to z = 0.50, and a slightly lower K-correction for galaxies in the interval 0.50 < z < 0.75, to account for the slightly bluer colors observed at $z \gtrsim 0.5$. However the K-corrections for our most distant galaxies, 3C 343.1 and Cl 1305 + 29 are very uncertain. Both galaxies are quite blue, and must have corrections below any extrapolation of Oke's values. We may estimate K-corrections for these galaxies from their observed energy distributions, as far as they go, or attempt to utilize the synthetic spectra of Pence (1976). We suggest utilizing Pence's Sab galaxy model to approximate the uncertain ultraviolet colors and color-evolution appropriate to a very distant E galaxy. This leads to bi-modal values of K_V for the two large-z galaxies.

Naturally, we are aware of the alternate concept, utilized by Gunn and Oke, who <u>observe</u> at wavelengths appropriate to <u>B</u> and <u>V</u> emitted frequencies. This procedure becomes very difficult at $z \gtrsim 0.6$; Table 1 lists the observed wavelengths for the nominal <u>B</u> and <u>V</u> bands as a function of redshift. The

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TABLE 1

OBSERVED POSITIONS FOR B AND V WAVELENGTHS FOR VARIOUS GALAXY REDSHIFTS

z	B	V	Notes
0.00	4400Å	5600Å	Rest wavelengths.
0.50	6600	8400	V in OH.
0.60	7040	8960	V in OH.
0.70	7480	9520	Both in strong OH.
0.80	7920	10080	Both in strong OH.
0.90	8360	10640	Both in strong OH.

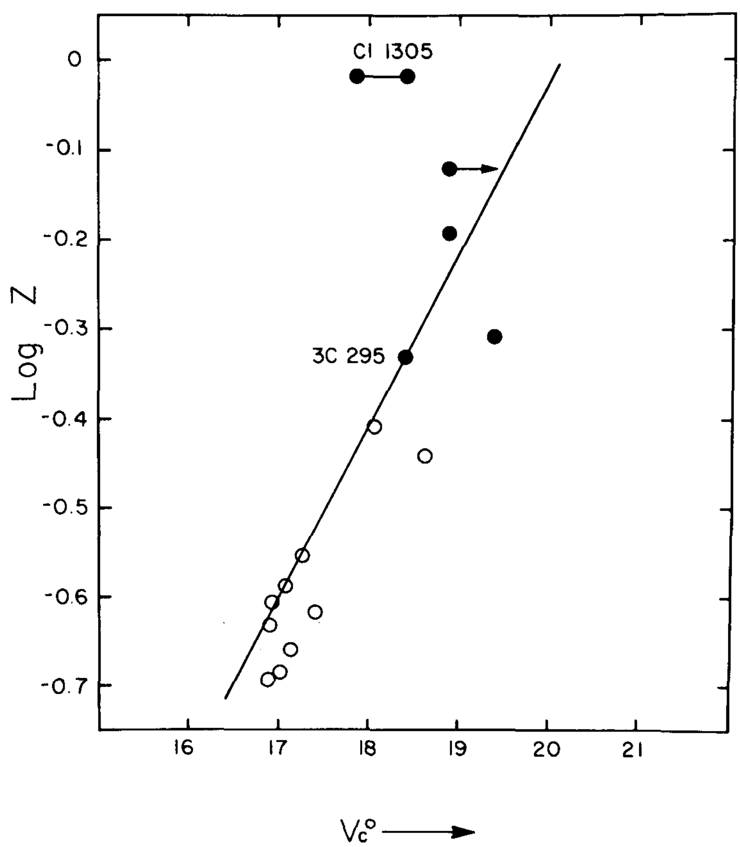

Figure 4.: A Hubble-diagram for faint galaxies using published cluster members (open dots) radio galaxies (closed dots), and Cl 1305+29 (z = .95). Photometry is photoelectric or calibrated photographic. See the text discussion for the multiple symbol explanation. The solid line has a Hubble slope of 5, arbitrarily through 3C 295.

emitted $\underline{V}$ band, in particular, is difficult to observe accurately in the near-infrared, where detectors are poor and the OH-plagued airglow foreground radiation is severely bright.

(c) We have employed Sandage's (1973) corrections for galactic absorption (A_V).

(d) Finally, we have not employed any corrections for cluster richness or Bautz-Morgan contrast class, as suggested by Sandage, Kristian and Westphal (1976, hereafter abbreviated as SKW). This is because we are pushing toward the limits of deep direct photography, to locate the most distant radio galaxies which sit at the top of the optical luminosity function. Our cluster member counts will not be nearly as "deep" into the cluster luminosity function at $z > 0.6$, as is possible for relatively nearby clusters.

The first Hubble diagram (Fig. 4) employs the SKW photometry of some clusters, the KSW photometry of faint radio galaxies, and Kron's calibrated photographic photometry for Cl 1305 + 29. A rough measure of the uncertain K-corrections for the two most distant objects are indicated by dual symbols for Cl 1305 + 29, and an arrow shows the reduced K_V which might be correct for the blue continuum of 3C 343.1. The dotted symbol for 3C 343.1 was placed with the Oke K_V. Our m, z correlation for very faint galaxies does not look as "tight" as the SKW Hubble-diagram, or that of Gunn and Oke. Some of our problems may be observational error, or large selection effects - but part of the qualitative difference could be real.

Our scanner photometry-Hubble diagram is shown as Fig. 5; the apparent $\underline{V}$ magnitude is of slightly lower photometric quality than conventional photoelectric data, but all the data indicated by closed circles is on a self-consistent system. A few less-accurate photographic magnitudes are indicated by crosses. The scatter around the Hubble-line (slope 5, arbitrarily through 3C 295 here - like a $q_0 = 1$ relation) is fairly large, with $\sigma_M = 0^m.7$. Fig. 6 shows a histogram of absolute magnitude residuals, with 3C 295 arbitrarily at zero. 3C 295 is only about a quarter-magnitude brighter than the average radio galaxy in this sample; recall the Gunn and Oke suggestion that it is $1^m.0$ brighter than their average first-ranked cluster member, while KSW place 3C 295 right on the Hubble "ridge line," or even on the low-luminosity side!

This bewildering array of systematic absolute magnitude differences

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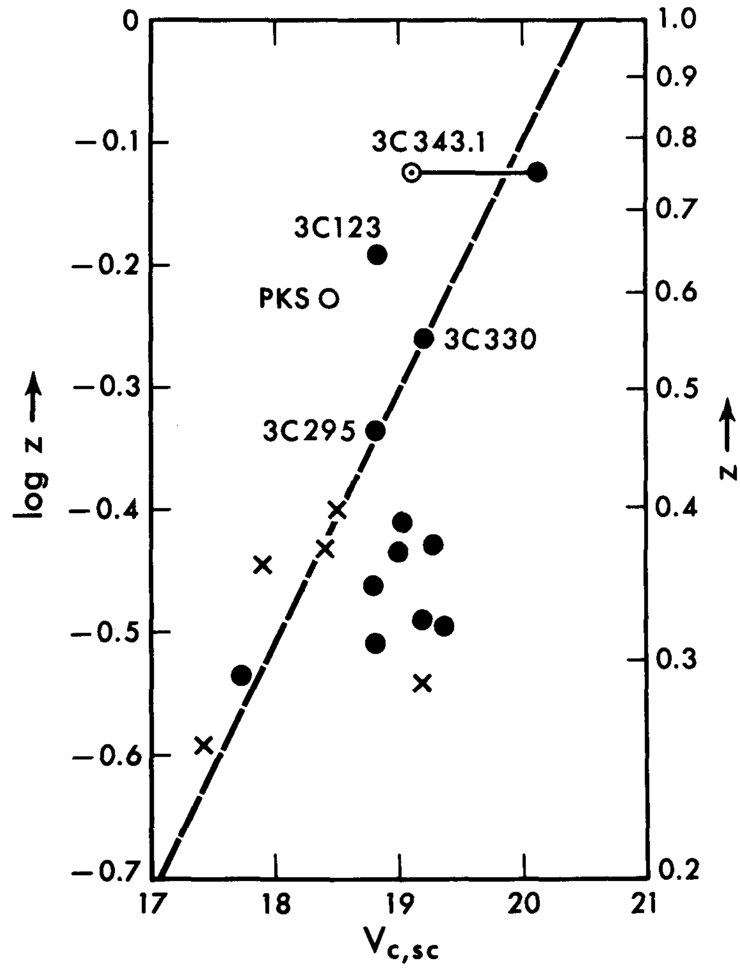

Figure 5.: A Hubble-diagram for faint radio galaxies using scanner magnitudes only. The straight line through 3C 295 is an arbitrary one with slope 5 (as for world model with q_0 = +1.). Crosses are galaxies with estimated photographic magnitudes, filled circles are scanner magnitudes, and the open circle represents PKS 0116+082, which may have a partly non-thermal continuum.

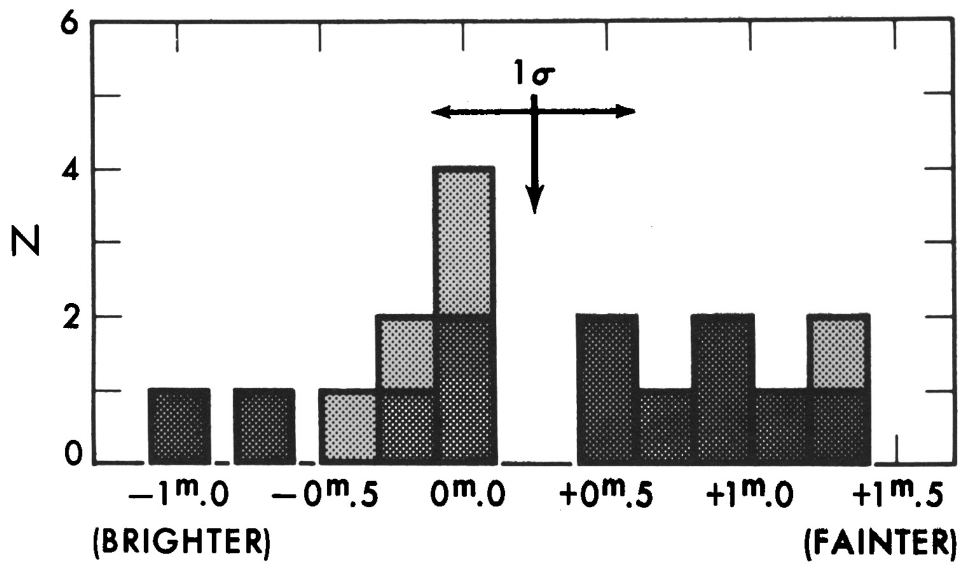

Figure 6.: Magnitude residuals from Fig. 5 (radio galaxy m, z relation), with zero point at the magnitude of 3C 295. Note the average radio galaxy is only about $0^{m}.25$ fainter than 3C 295, in our sample. The dispersion is fairly large, with $\sigma_M = 0^{m}.7$. The solid hatchings are galaxies with scanner magnitudes, open hatch histogram bars are from the photographic estimates. 3C 343.1 and PKS 0116+082 were omitted from this diagram.

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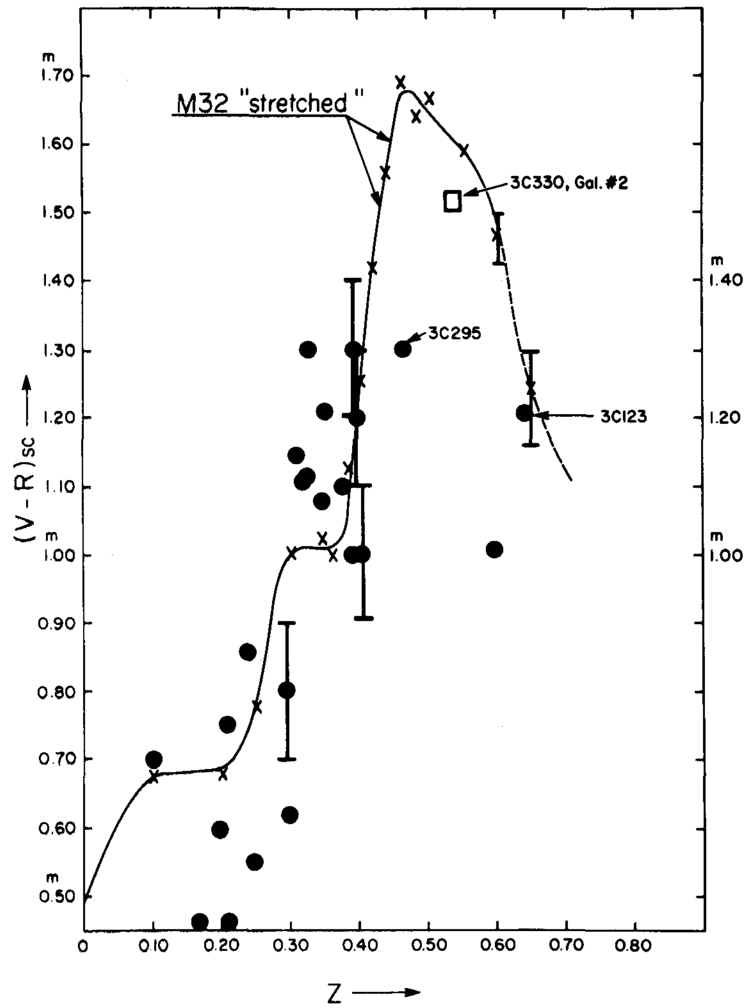

Figure 7.: Colors of faint radio galaxies (filled dots) and one bright non-radio E (3C 330 #2, the square symbol) in the scanner (V-R) color system. Note that galaxies at z > 0.4 seem bluer than the standard curves - this normal relation which was computed by stretching the M32 nucleus spectrum.

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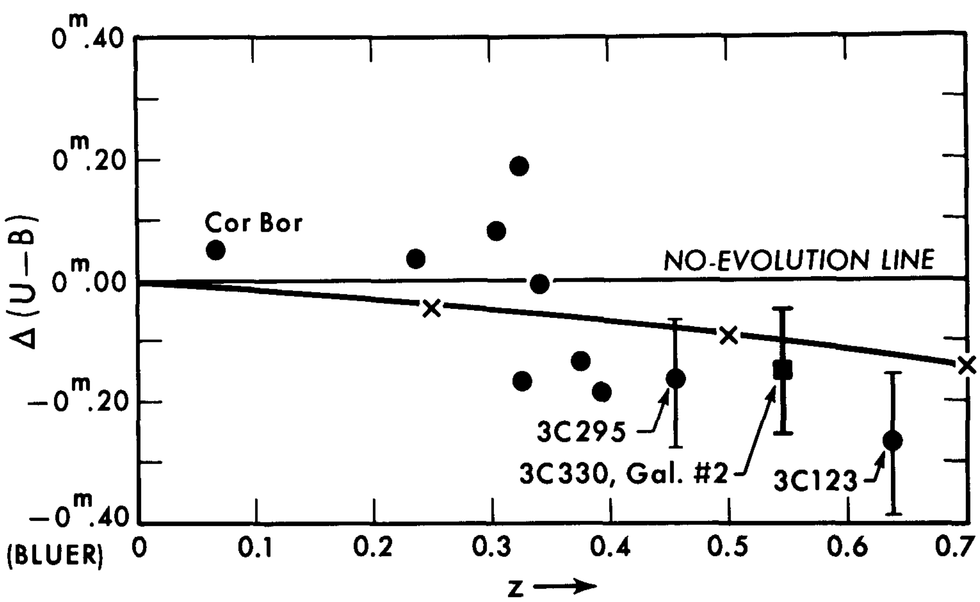

Figure 8.: Galaxy colors, plotted as (U-B) scanner magnitude residuals, all in the appropriate rest frames. M32 is again the reference standard. Note that beyond z > 0.4, all galaxies are bluer than M32. The curved line connecting X's is the expected locus for Tinsley-Gunn models with x = 1, and a single, early burst of star-formation.

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for 3C 295, and presumably other galaxies, must have a rational explanation, although we do not claim to be able to resolve the quandry. There must be substantial differences of object selection and some systematic differences in galaxy magnitude corrections. Which are the correct procedures? We just don't really know, and this concern, along with the ever-present large luminosity evolution corrections (Tinsley - this Colloquium), make an attempt to determine q_0, the deceleration parameter, premature, despite the large-redshift galaxies observed. If anything can be derived from our figures 4 and 5, it would be the impression that the apparent value of q_0 is larger than unity.

III. RADIO GALAXY COLOR-EVOLUTION

Following the work of Oke (1971) and Crane (1975), Spinrad (1976) recently compared scanner (V-R) colors of faint galaxies with a model, computer-redshifted from our observed M32 spectrophotometry. The M32 nucleus is the best available simulation of the integral light from a normal giant E galaxy. The galaxies at $z > 0.45$ were all somewhat bluer than expected. Fig. 7 shows an updated plot of the standard (V-R) colors (solid-line) from rest to $z = 0.6$, after which they become uncertain; individual radio and non-radio galaxies are also shown.

However, a more logical way to compare the colors of galaxies at various redshifts is to place the spectra back into the emitted light rest frame, as was done for 3C 123 in Fig. 3. Fig. 8 shows the galaxy rest-frame $(U-B)_{SC}$ residuals, compared to the M32 nucleus again. Using the nucleus of NGC 4472 would have placed the zero-line $0^m.12$ higher. Note that the high-z galaxies, both radio emitters and the normal E galaxy which is second-ranked in the 3C 330 cluster (Spinrad *et al*. 1976), are systematically bluer-than-normal at $z > 0.4$! We also have plotted a rough analogue of a single-generation star-formation model of Tinsley and Gunn (1976). The usual ambiguity between elapsed time and z makes our comparison schematic, but the rough color-evolution agreement is encouraging. It also provides further motivation toward observing other galaxies at $z > 0.6$.

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However, it is overly optimistic to expect easy observational differentiation of evolutionary models with mass-function power-law spectra with distant galaxy color data. Only marginally different (U-B) colors are predicted for x = 0 and x = 2 (Tinsley, 1975).

However, at our largest redshifts, and at shorter emitted wavelengths, we may be able to look at the relatively rapid stellar evolution of main-sequence F stars, if galaxies form at $z_f < 5$. In fact, a galaxy colors at $\lambda_0 < 3000$ should be capable of distinguishing their epoch of formation (z_f), to fair precision (Tinsley 1976). That statement is, naturally, model-dependent; we have to assume the standard Tinsley-Larson model without subsequent bursts of star-formation to confuse the initial decay of hotter young stars after formation. A problem here is one of local comparison; what is the average nearby E galaxy spectrum over $\lambda\lambda_0$ 2000-3000 ? The only rough answers yet available come from the satellite photometry by Code, Welch and Page (1972), Code and Welch (1975), and new, unpublished data by the ANS observers. In each case, the observations are difficult, and calibration errors are possible. An alternate, and unproven procedure for synthesis of E galaxy spectral energy distributions is to attach portions of middle-F star spectra to the 3C 295 energy distribution (Oke 1971).

The scanner observations of 3C 123, 3C 330 #2, and Cl 1305 + 29 are marginally available to λ_0 2600Å (and below for the cluster 1305 galaxy). They are all flatter in F_ν over rest $\lambda\lambda_0$ 3000-2600 than is the Copernicus satellite spectrophotometry of the F5 star, α CMi (Morton et al., 1977). It would even seem feasible to check for an upturn in the emitted ultraviolet below 2000Å, by calibrated photographic photometry at $z > 0.8$; it is an attractive speculation that Kron's newly-found faint blue clusters are at redshifts around unity, and their colors might indicate the presence of hot stars in the distant galaxy spectra.

IV. PRELIMINARY SURFACE BRIGHTNESS MEASURES: GALAXY LUMINOSITY EVOLUTION

In a colloquium concerned with the expansion of the Universe and galaxy evolution it may be appropriate to discuss a measurement which involves both subjects.

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We should be able to evaluate distant galaxy luminosity evolution (stellar and dynamic), and test the hypothesis of redshift ≡ expansion, through appropriate surface-brightness measures. The technique is conceptually simple. Standard galaxian surface brightness, measured at a fixed metric distance from the E galaxy center, depends only upon the recession terms; $(1 + z)^{-3}$ is appropriate for the recessional dimming when measured monochromatically and K-corrected (c.f. Sandage 1974, Petrosian 1976 and Tinsley 1976, 1977). However, luminosity evolution, dL/dT, will also be important at the redshifts we consider. The expansion terms are inseparable from luminosity evolution in galaxy surface brightnesses. We can either assume the expansion dimming and solve parametrically for dL/dT as a function of q_0, or we may invert the procedure, assume Tinsley's evolutionary models, a particular deceleration parameter, and solve for the expansion term power. The dependence upon q_0 arises from the need to convert a metric radius to an observable angular distance.

A pilot program to examine the practical aspects of this research has begun; we traced the photographic images of three galaxies in each of two distant clusters with the Berkeley PDS microphotometer, using a 20μ square slot. This aperture projected to 0".37 on a side, on the original high quality KPNO 4-m red plates. Fig. 9 shows the linearized and slightly smoothed radial profile of the galaxy 3C 330; the second-ranked galaxy in this cluster had virtually the same shape. The other cluster (Cl 0024 + 16, z = 0.392) galaxies were somewhat brighter and larger. Except for their cores, these profiles resemble Hubble's law ($I \sim r^{-2}$), and can be observed to about r = 4". The seeing was good on these plates; a nearby faint star profile is only at 1.5% of its maximum intensity at r = 3".0 radius. Nevertheless, small convolution corrections were made to the galaxy surface brightness values.

We have chosen a reference metric radius, R = 25 kpc, to compare the E galaxy surface brightnesses. For $q_0 = 0$, this corresponds to r = 3".0 at 3C 330, to r = 4".0 at Cl 0024 + 16, and r = 37" at the Coma cluster (z = 0.022). The initial absolute zero-point for our surface photometry was determined by the red-region sky surface brightness at KPNO ($\overline{m_r} = 21^m.2 \pm 0^m.4$); this value was iterated and improved by forcing the integrated galaxy magnitude within the appropriate projected circle on the PDS frame to equal the independently observed photometric magnitude for the brightest galaxy

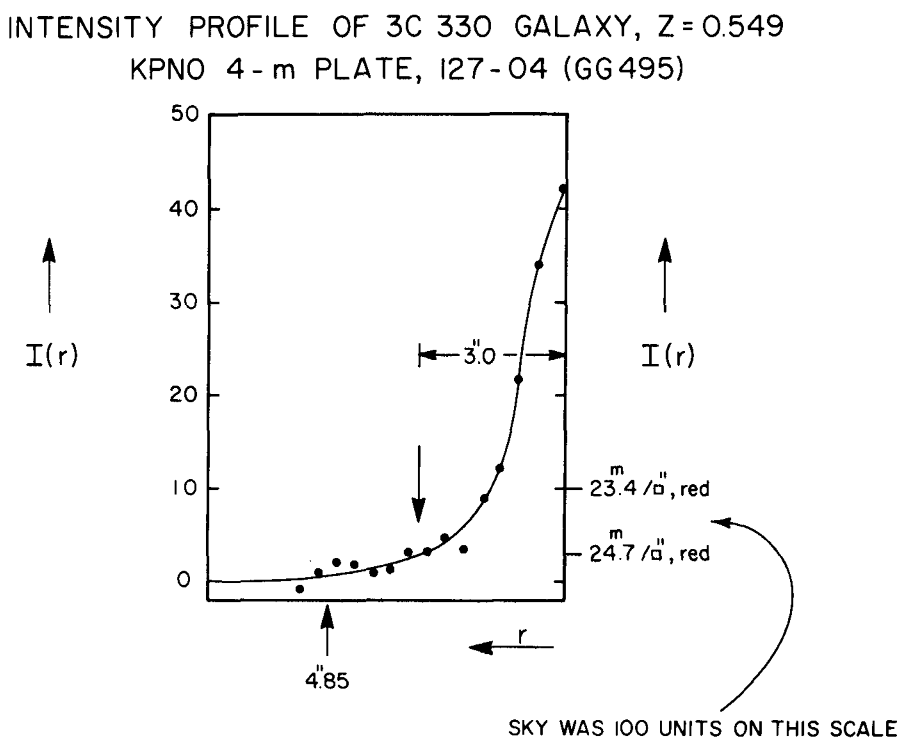

Figure 9.: The radial luminosity profile (on a linear scale) for the galaxy associated with 3C 330. This is used to obtain the galaxy surface brightness at a fixed metric distance, as explained in the text.

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in each cluster. The internal uncertainty in our surface brightness scale still could easily be $0\overset{m}{.}2$.

Table 2 compares the two distant clusters (BM types III) with representative (hopefully) similar bright cluster galaxies in Coma and Virgo. Here we used unpublished photometry due to King and Oemler, and apparently the uncertainties in the nearby E galaxy surface brightnesses are not really negligible. The Table 2 example is illustrative for $q_o = 0$; we have also compared these galaxies with larger assumed q_o values, as shown in Table 3. For small q_o, where our local prejudice lies, the mean evolutionary magnitude difference is $0\overset{m}{.}75$. This would translate to $\Delta q_o = 1.5$, rather close to Tinsley's prediction in this Colloquium. The sense of the observed difference is that E galaxies were considerably brighter in the past, in their relative youth.

The model-dependent inversion of our method to check on the $(1 + z)^{-n}$ exponent yields $\bar{n} = 2.5 \pm 0.5$ for $q_o = 0$, and about $n = 2$ for $q_o = +1/2$. We recall that the monochromatic dimming due to a true expansion of the universe should go as $(1 + z)^{-3}$, while the "tired-light" model of Geller and Peebles (1972) would demand $n = 0$.

The result also limits the amount of intergalactic absorption (to $z = 0.5$), if we accept both the sense of Tinsley's evolutionary corrections, and the now-popular low value of q_o. An estimate would be $A_V < 0\overset{m}{.}5$.

These interesting surface-brightness results are still to be considered tentative, but we plan future observing of distant clusters on plates with better-determined sky zero-points. However, a problem of which Bautz-Morgan cluster classes to compare (use or avoid dD profiles?) might complicate the issue.

V. CONCLUSIONS AND FUTURE PROSPECTS

There is little doubt that the next few years will lead to measurements of the redshifts of yet fainter galaxies, both radio sources and simply those in clusters. These data will extend the Hubble diagram, and give us colors of even "younger" stellar systems. However, the deceleration parameter

TABLE 2

COMPARISON OF GALAXY SURFACE PHOTOMETRY, $q_o = 0$

Galaxy	3C 330 #1	Cl 0024 + 16 #1	N4889	N4472	M87
z	0.549	0.392	0.022	0.003	0.004
$^*VSB_{25}$	$25^m.6$	$25^m.1$	$23^m.3$	$23^m.4$	$23^m.7$
$(1+z)^{-3}$	$-1^m.42$	-1.08	-0.07	0	0
K_V	$-1^m.65$	-1.20	-0.03	0	0
SB°_{25}	$22^m.5$	$22^m.8$	$23^m.2$	$23^m.4$	$23^m.7$
$\Delta m(SB^\circ-23.4)$	$-0^m.9$	$-0^m.6$	$-0^m.2$	$+0^m.0$	$+0^m.3$

* VSB_r is the observed visual surface brightness at metric distance of r kpc from the nucleus, including a small seeing-correction ($<0^m.1$).

TABLE 3

EVOLUTIONARY SURFACE-BRIGHTNESS MAGNITUDE DIFFERENCES FOR THREE DECELERATION PARAMETERS

Cluster	z	$q_o = 0$	$q_o = +1/2$	$q_o = +1$
3C 330	0.549	$-0^m.9$	$-0^m.7$	$-0^m.5$
Cl 0024 + 16	0.392	$-0^m.6$	$-0^m.4$	$-0^m.2$

will not come easily in this way; evolutionary corrections will be harder to apply to emitted ultraviolet wavelengths. Other cosmologic tests will have to be conceived.

It is our hope that measures of galaxy cluster characteristic sizes, say. their core-radii, will yield a value for q_0, through the metric-rod, angular size dependence. The pioneering work of Bahcall (1971, 1973) and Hickson's slightly new procedure (1976) may be successful when applied to enough clusters locally and at $z \gtrsim 0.5$. G. Bruzual at Berkeley has begun re-evaluation of the emthods, hoping that they may be applicable to the most distant clusters with redshifts, when only a modest number of likely cluster members appear over the field galaxy background.

Cosmologic utilization of galaxy cluster sizes depends upon an evaluation of the dynamical evolution (possible size change) of clusters over the past 6-9 billion years; conceivably another kind of evolution could conspire to hide cosmological answers from us again, but we hope not!

This work has been generously supported by grants from the NSF, through AST 72-05061 to Berkeley, and AST 74-19471 to San Diego.

We wish to acknowledge useful discussions with Bea Tinsley, Allan Sandage, Richard Kron, Ivan King, Jerome Kristian and Goeff and Margaret Burbidge. We also thank Drs. Oemler, Willis, and Code for sending us unpublished data.

We are also grateful to the staffs of the Lick and Kitt Peak Observatories for their assistance.

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DISCUSSION

E.J. WAMPLER: In reference to your slide showing the change of color with redshift do you think that the observed deviation could be caused by one or more of the following observational effects:

1. The change of effective aperature with z.
2. Possible atmospheric dispersion.
3. A possible tendency to overestimate the strength of noisy data that cannot have values below zero.

H. SPINRAD: These effects are possible, and could conspire to lead to apparently bluer galaxies at large z. However the dispersion effect at observed long wavelengths is small, and the aperature effect should be larger over the range z = 0.2 to 0.4 than over 0.4 to 0.6, where Δ(U-B) increases. So I do not think they are responsible for the blueness of galaxies at z > 0.4.

V. PETROSIAN: I would like to stress, as Dr Tinsley did, that the relation between redshift and surface brightness within a metric radius (for an assumed q_o) does not contain any more information than the redshift - magnitude relation. Only the average isophotal surface brightness (or some variation of it) is independent of the cosmological model and can be used for determination of evolution of galaxies or for distinction between expanding and tired light models.

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H. SPINRAD: You are conceptually correct, but since these are quite independent of the published Hubble diagrams, it would seem useful to consider them.

M.S. ROBERTS: Your Hubble diagram appears to be better fit by a vertical line rather than by a line with a slope of 5. Would you comment?

H. SPINRAD: I comment (reluctantly) that the slope of the Lick data Hubble-line would suggest an apparent $q_o > 1$. In part this must be object selection effects, plus the need for a Malmquist-type correction.

P. VERON: In your diagram showing the U-B excess versus redshift, you have included 3C 123 which is at low galactic latitude and is probably heavily reddened. How have you estimated this correction and which value have you used?

H. SPINRAD: The reddening in front of 3C 123 was estimated from foreground stars, and I used $E(B-V) = 0^m\!.15$. This value needs improvement; if the reddening is larger, it will make the $\Delta(U-B)$ color excess for 3C 123 somewhat greater.

M. ROWAN-ROBINSON: Can you set a limit on the contribution of non-thermal emission to the continuum in these large redshift radio-galaxies?

H. SPINRAD: The non-thermal optical contribution at λ_o 4000 to these "normal" radio-galaxies is small, probably less than 20 %.

B. PETERSON: For what fraction of these faint galaxies that you have observed, was it possible to obtain redshifts?

H. SPINRAD: About one-half.

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