INFRARED OBSERVATIONS OF ELLIPTICAL GALAXIES

M. J. Lebofsky
Steward Observatory, University of Arizona, Tucson, AZ 85721

Abstract

A program to search for luminosity evolution of giant elliptical galaxies at high redshift has been begun at 2.2μm. Observing at infrared wavelengths offers the possibility of avoiding large and uncertain K corrections at redshifts near 1. First results of this program are in agreement with conclusions drawn from much larger optical studies, and demonstrate that luminosity evolution may be present.

I. INTRODUCTION

Giant elliptical galaxies have served as the standard candles in studies aimed at measuring cosmological parameters such as q_0, but whether the luminosity of these galaxies is actually constant or whether galaxies were more luminous in the past is not known. Various theoretical considerations (e. g. Tinsley 1977) indicate that galaxies should have been brighter in the past, and the observation of strong CO bands in nearby ellipticals (Frogel et al. 1978) supports this contention (Tinsley 1978); Sandage (1961) was the first to consider the effect of luminosity evolution on attempts to determine q_0. His conclusion then was very similar to that of Kristian et al. (1978): that either $q_0 \sim 1$ and galaxies do not show any luminosity evolution or $q_0 \sim 0$ and galaxies are about ~ 0.5 mag dimmer now than at 5×10^9 years ago. Many corrections are required to derive these results from optical data; some of the same corrections are required for an analysis of the infrared data but some such as the K correction (very uncertain for optical magnitudes as $z \to 1$) are more secure in the infrared.

Because of the possibility of detecting galaxy evolution and checking optical measurements, a program of measuring the brightest cluster ellipticals has been started with observations made principally at K (2.2μm). This wavelength has the advantage that the portion of the galactic energy distribution which is redshifted into

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the filter pass band is well-measured in nearby galaxies for redshifts even larger than 1. Other useful features are the relative flatness of the near-infrared energy distribution of ellipticals, the uniformity of the near-infrared colors, and the lack of aperture dependence on the near-infrared colors, all of which make the K corrections small and well-determined. This paper presents the first observations at 2.2μm of 6 giant elliptical galaxies ranging in z from 0.136 to 0.947 with a preliminary analysis of the results.

II. DATA

All measurements were obtained with the Steward Observatory 2.25 meter (90 inch) telescope equipped with a liquid helium-cooled InSb photometer. The data were obtained at K (2.2μm) and also at H (1.6μm) for most galaxies; Table I presents the data and the apertures used. Standard infrared chopping techniques were used but no corrections for galaxy flux in the reference beam were made because such corrections were estimated to be less than 4% in all cases. All measurements were made using offset guiding using position measurements derived from Palomar plates for the galaxies and nearby stars. The V band data used in deriving the V-K colors in Table II are from Gunn and Oke (1975) or Kristian et al. (1978). The K corrections for the V data were taken from Whitford (1975) through z = 0.46 and from the plots in Code and Welch (1977) for the companion to 3C330.

Before the infrared data can be used for absolute magnitude estimates or for cosmological analyses, several corrections need to be considered. Since this paper is only a first examination of a small number of measurements, only preliminary values have been derived for some of these corrections. In particular, the energy-dependent portion of the K correction has been derived using a smoothed galaxy energy distribution and rectangular approximations to the filter functions. This portion of the K correction at 2.2μm is never larger than 0.28 mag so the uncertainty introduced by using this approximate K correction is small.

Table I. Photometry of Giant Ellipticals

	Z	H (1.6μm)	K (2.2μm)	Aperture (")
UMa II, Cl.1	0.136	14.79±0.09	14.56±0.06	5.9
Hydra, G8+G9	0.202	15.43±0.08	15.21±0.08	7.8
1318.1+3157	0.270	15.37±0.08	14.60±0.06	7.8
1613+31	0.415	16.25±0.13	15.38±0.09	7.8
3C330, companion	0.532		16.22±0.13	7.8
1305+2952	0.947		$17.77^{+0.82}_{-0.46}$	7.8

The aperture correction was derived by assuming a fixed diameter of 86 Kpc and using the 2.2μm curve-of-grow in Frogel et al. (1978) and following a procedure similar to that outlined in Sandage (1972a). This choice of diameter was made for ease in comparison of absolute magnitudes with those derived by Sandage and others at V where $< M_V > \sim -23.3$ which yields $< M_K > \sim -26.6$ (V-K $\sim$ 3.3 [Frogel et al. 1978]) for 86 Kpc, $q_0 = 1$, and $H_0 = 50$. As discussed by Kristian et al. (1978), the aperture correction has only a small dependence on q_0; however the conversion of linear diameter to aperture size depends linearly on the value of H_0 (see equations in Sandage 1972a) so the data have been reduced using two choices (50 or 100 Km/sec/Mpc) for H_0 and two choices for q_0 (0 or 1). Since the main objective at this time is to see whether galaxies are brighter at high redshift, this method will provide acceptable aperture corrections, but zero-point shifts will exist between the different choices of H_0 and q_0. The most appropriate galaxy diameter to use will be considered more carefully in a later paper.

The corrections usually applied for interstellar absorption within our galaxy will not be used since $A_K \sim .1\ A_V$. The corrections for Bautz-Morgan contrast class and richness class usually applied by Sandage and his co-workers (Sandage and Hardy 1973; Kristian et al. 1978) have not been used because it is not yet clear whether such corrections are applicable at 2.2μm.

III. DISCUSSION

The small number of sources measured so far in this program precludes any definitive discussion of whether luminosity evolution has been detected. However, a brief consideration of these results will show the potential of 2-μm measurements for studying properties

Table II. Colors and Absolute Magnitudes

				M_K			
				q=0		q=1	
	Z	$(V-K)_c^*$	$(H-K)_c$	H=50	H=100	H=50	H=100
UMa II, Cl.1	0.136	2.89	0.03	-25.9	-25.0	-25.8	-24.9
Hydra, G8+G9	0.202	2.37	-0.09	-25.4	-24.7	-25.5	-24.5
1318.1+3157	0.270	3.89	0.40	-26.8	-25.8	-26.6	-25.6
1613+31	0.415	3.26	0.33	-27.0	-25.9	-26.7	-25.6
3C330, companion	0.532	3.05		-26.9	-25.7	-26.4	-25.2
1305+2952	0.947			-27.3	-25.9	-26.5	-25.3

* V magnitudes from references in text.

of galaxies at high redshift. The 2-µm Hubble diagram is shown in Figure 1 fit with a line appropriate to the $q_0 = 1$, $H_0 = 50$ case which was chosen because the choice of 86 Kpc as the physical diameter used in computing the aperture correction is correct only for these choices of q_0 and H_0. The constant was calculated by minimizing the residuals. The observed points are well-represented by a linear fit demonstrating that the infrared data follows the same general behavior as optical data--there are not infrared excesses or other unexpected properties destroying the usefulness of these measurements.

The absolute magnitudes at K(2.2µm) and $(V-K)_c$ and $(H-K)_c$ colors derived from the data are presented in Table II. The H-K colors have an uncertainty of 0.10 mag while the V-K colors are uncertain by 0.15 mag. Since the main purpose of this initial investigation is to determine what infrared measurements will reveal, the values in Table II will be discussed in terms of what problems or general trends the data show.

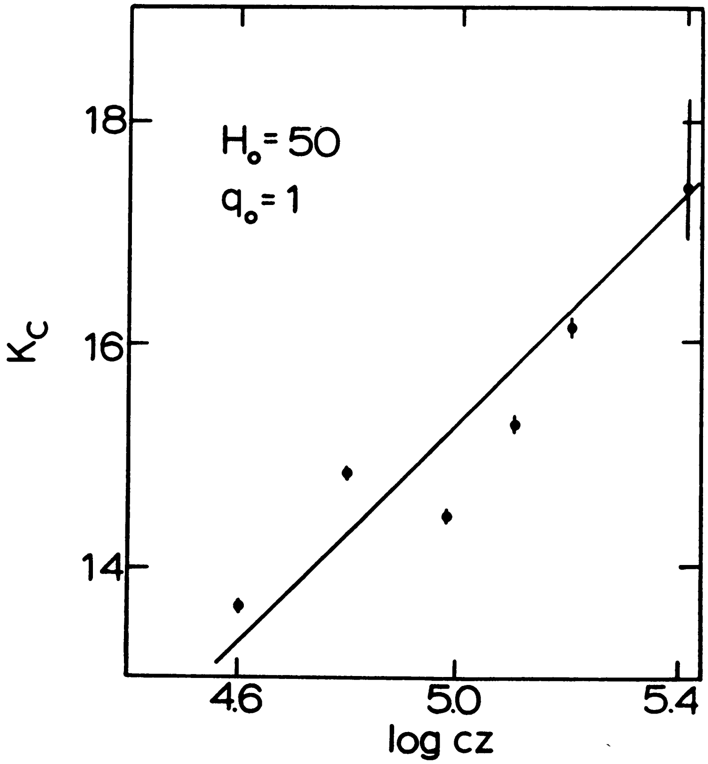

Figure 1. The infrared Hubble diagram with the data fit by the line $K_c = 5 \log cz + C$, $C = -9.72$, (Sandage 1972b).

One problem evident from Table II is that the measurements of Hydra are anomolous--the colors are too blue and the total K flux is too small. More observation will be required to learn if this galaxy is peculiar. The other abnormal color in Table II is the very red V-K color of 1318.1+3157. The H-K color of this galaxy is redder than the normal H-K ∿ 0.22 for ellipticals, but it is only 2σ away from the nominal color. One possible explanation for the red colors is absorption by intergalactic dust; this explanation is supported by the 2.2μm absolute magnitude which is close to the nominal value of -26.6 in the H_0 = 50 q_0 = 1 case. Another possibility is that the galaxy has an infrared excess although the absolute magnitude does not support this.

The surveys at optical wavelengths of cluster ellipticals (e. g. Kristian et al. 1978) have come to the conclusion that either q_0 is near 0 and galaxies were brighter in the past or that $q_0 \geq 1$. The absolute magnitudes in Table II support a similar conclusion from the infrared data, but a larger sample will have to be studied before any stronger statements can be made. A sample large enough to circumvent the intrinsic scatter in absolute magnitudes and colors will be needed as will a resolution of why some galaxies such as 1318.1+3157 have such red colors.

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DISCUSSION

Ellis: What is the scatter in the infrared colours for ellipticals at zero redshift?

Lebofsky: The scatter in the V-K colors at zero redshift is ~ 0.3 magnitude for giant ellipticals. The dispersion in the H-K colors is only about 0.05 magnitude. The larger scatter in the V-K color may not reflect a cosmic dispersion but may only reflect scatter introduced by calculating colors from data taken with different apertures, etc.

Peebles: How long does it take you to measure the apparent magnitude at 2μ and redshift ~ 1? Is it feasible to count galaxies in blank fields at 2μ at this depth?

I might note that the absolute magnitudes you compute at $H = 50$ and 100 km s^{-1} Mpc^{-1} should differ by just 5 log 2 because H is just a scale factor.

Lebofsky: The 2.2 μ magnitude at $z = 1$ takes about three hours to measure with a 90-inch telescope. Since 1305+2952 may be unusually blue, other galaxies at $z = 1$ may be measured more accurately or in less time, and the availability of larger telescopes such as the MMT will also speed the observations. A carefully designed experiment might be able to count galaxies at $z = 1$ at 2.2 μ over limited areas of the sky.

The computed absolute magnitudes do not differ by 5 log 2 because the product of H_O and linear diameter used in the aperture correction was not held constant; the linear diameter was held constant independent of H_O. Holding the diameter constant then produced aperture corrections which have an unphysical dependence on H_O and produced the differences you noticed in Table II. A more careful consideration of the aperture correction will use a linear diameter appropriate to 2.2 μ observations and will not depend on H_O.

Schild: Can you tell us what the sky brightness is in magnitudes per square arc sec at 2.2 μ?

Lebofsky: The sky brightness at 2.2 μ is produced by thermal radiation from the sky and telescope and depends on the temperature and the emissivity of both the sky and telescope. For a typical temperature and an emissivity appropriate to a low background telescope, $K \simeq +17$ per square arc sec. For the fields of view used in this work, this corresponds to a detector N.E.P. of about 10^{-16} watts $Hz^{-1/2}$ at 2.2 μ.