STELLAR CONTENT OF THE NUCLEI OF ELLIPTICAL GALAXIES

DETERMINED FROM 2.3-μ CO BAND STRENGTHS

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ABSTRACT

Observations of the luminosity-sensitive CO absorption band at 2.3 μ are presented for the nuclei of 16 E and S0 galaxies. Preliminary data on the radial variation of the CO index in 6 galaxies are also given. The data show that the 2-μ radiation from the nuclei is dominated by high luminosity stars of integrated spectral type later than K5. There is only a small variation in the CO absorption from galaxy to galaxy, and only a slight variation with measuring aperture size from 17".5 to 59". The data can be used to synthesize stellar populations for elliptical galaxy nuclei.

I. INTRODUCTION

In previous papers, Baldwin, Danziger, Frogel, and Persson

(1973a), and Baldwin, Frogel, and Persson (1973b) presented

photometric measurements of the 2.3-μ CO absorption band in

stars, and demonstrated that the strength of this band depends

on spectral type and luminosity in stars later than K0. Observa-

tions of the nuclear regions of the Sb galaxies M31 and M81

showed that from 2.0 to 2.4 μ the radiation of these galaxies

is probably dominated by late-type giants. Because of its sensi-

tivity to the luminosity of the late-type stellar component,

the CO band strength is an important parameter for the construction

of stellar synthesis models of elliptical galaxies (Faber 1972).

In addition, if a large enough measuring aperture is used, the

synthesized stellar model can yield information on the evolutionary

correction to q_o, the cosmological deceleration parameter

(Tinsley 1973). This Letter presents preliminary observations

of the nuclear regions of 16 E and S0 galaxies and a report

on the radial variation of the CO parameter in 6 of these galaxies.

It was considered worthwhile to present these results now because

of interest shown in them and in their potential significance

with regard to the stellar content of galaxies and related

cosmological questions.

II. OBSERVATIONS

The observations described in this paper were made in Arizona with the 2.1-m telescope on Kitt Peak and the 1.5-m telescope on Mt. Hopkins, and at the Hale Observatories using the Mt. Wilson 60-inch telescope and the Palomar 200-inch Hale Telescope. The data were obtained with two photometric systems similar to but different from that described by Baldwin et al. (1973b). These new systems increase the discrimination between giant and dwarf stars by 0.07 mag at MO, compared to the system of Baldwin et al. (1973b). The measurements made at the Hale Observatories were obtained with an InSb detector and filters at 2.38μ ($\Delta\lambda = 0.08\mu$) and 2.2μ ($\Delta\lambda = 0.13\mu$). At Kitt Peak a PbS detector and filters at 2.36μ ($\Delta\lambda = 0.08\mu$) and 2.20μ ($\Delta\lambda = 0.08\mu$) were used. The $[2.4\mu] - [2.2\mu]$ color measures the depth of the CO absorption band near 2.4μ.

A large number of stars covering the relevant range of spectral type was observed on all three photometric systems – the two new ones and that of Baldwin et al. (1973b). For all types of stars it was possible to perform a simple transformation between the CO indices, defined as the $[2.4\mu] - [2.2\mu]$ color, of the two new systems. Since most of

the galaxy measurements were made at the Hale Observatory

telescopes, all the present data were transformed to that

system and are presented in figure 1. A satisfactory one-to-one

transformation was also found to exist between the indices measured

with the two new systems and those measured with the system

of Baldwin et al. (1973b) for giant and supergiant stars. Thus

figure 1 includes all the luminosity class III and brighter

stars previously observed with the system of Baldwin et al. (1973b)

plus an additional 17 supergiants in h and χ Persei observed

with that system. The error introduced by the transformations

is much less than the intrinsic dispersion in the CO index at

a given spectral type.

The galaxy observations were made with circular, focal

plane apertures centered on the optical nuclei. The aperture

diameters were 59" on the Mt. Wilson 60-inch, 50" on the 2.1-m,

40" on the Mt. Hopkins 1.5-m and 17".5 on the 200-inch.

The "reference" beam was centered two-and-a-half aperture

diameters away from the center of the "signal" beam. Since

the flux in the reference beam was much less than 10 percent

of the flux in the signal beam, no correction was applied.

All of the galaxy measurements are plotted in figure 1 and

given in table 1. Note that only one galaxy, NGC 221 = M32,

was measured on the system of Baldwin et al. (1973b).

To reduce the systematic errors, a grid of 9 stars was chosen as standards with the criteria that they bracket the expected colors of the galaxies and that they be close to the galaxies in the sky. At least three of these stars were monitored throughout any night that galaxies were being observed.

The errors quoted in table 1 are the one standard deviation of the means presented; they result mostly from detector noise. There are additional systematic errors in the photometry. For point sources, repeated measurements of the standards indicated that the error in the index was less than ± 0.01 mag. Sampling of the CO index across the focal plane diaphragm indicated variations as large as ± 0.02 mag. Care was taken to observe standard stars at a position on the diaphragm which corresponds to the average index over the diaphragm; therefore, the transfer from an extended galaxy to stars should not contain a systematic error of more than 0.02 mag. Systematic errors which may arise from the difference in the effects of guiding and seeing on the images of stars and galaxies are estimated in all cases to be less than 0.01 mag.

Corrections to the CO indices for the galaxy redshifts were calculated from the known filter response curves and by assuming that the galaxy energy distributions are similar to that of a K5 III star (Frogel 1971). This procedure is

justified in the discussion below. For z ≤ 0.01 the correction

is < + 0.005 mag in the CO index and has been ignored. For

NGC 6702 the correction is + 0.025 mag, and for NGC 4889 it is

+ 0.060 mag. These corrections have been applied in figure 1.

Supplementary broad-band data at the conventional infrared

bands at 1.25, 1.65 and 2.2 μ were obtained of the central 59"

of 10 galaxies; these data will be published separately.

III. DISCUSSION

The main results of the observations are apparent from

figure 1 and table 1: the mean strength of the CO band in the

galaxies excludes the dominance of dwarf stars and corresponds

to late K to early M giant stars; there is a spread of less

than 0.1 mag in the CO index between the galaxies; and there

is no striking dependence of CO index on measuring aperture

size for individual galaxies.

It is important to assess the effects of abundance-variations

on these results. As pointed out previously (Frogel 1971,

Baldwin et al. 1973b), the CO band which is measured by the

CO index is most likely saturated, and even large changes

in the CO abundance in stars should have no observable effect.

In this regard, Ridgway (1974) has explicitly demonstrated

that the strength of this band is not sensitive to metallicity

effects in early K-giants. In addition, the sample in figure 1

includes both super-metal-rich and metal-poor stars, whose CO

indices do not differ systematically from the mean. Thus any

difference in CO band strength observed, either radially in one

galaxy, or from galaxy-to-galaxy, would necessarily be due to

a change in stellar population.

The recent results of Whitford (1973) and O'Connell (1974)

are in agreement with the conclusion that high luminosity stars

dominate the radiation of the nuclei of elliptical galaxies.

These authors rule out dwarf-enriched models by measuring the

strengths of the Wing-Ford band at 9910 Å (Whitford 1973) and

the Ca II + TiO features near 8500 Å (O'Connell 1974).

The broad-band measurements were used in an attempt to

determine the effective spectral types of the galaxies in

1 to 2-μ region. The spread in the colors observed was only

slightly greater than expected from the errors of the measurements,

and, although the data are very limited, the colors do not depend

on aperture size. The mean colors for the ten galaxies are

$[1.25 \ \mu] - [2.2 \ \mu] = 0.97 \pm 0.03$, and $[1.65 \ \mu] - [2.2 \ \mu] = 0.21 \pm 0.02$.

From Johnson's (1966) tabulation of stellar colors, these means

imply a spectral type between K5 and M5 for giant-dominated

light. A comparison of the 2.2-μ magnitudes with published

V magnitudes measured with similar sized apertures, shows that

V - $\left[2.2 \mu\right]$ ranges from 3.2 to about 3.4, which corresponds

to K4 - K5 giants. Thus, the dominant spectral type contributing

to the 2.2-μ radiation cannot be any earlier than this.

The observations made with the 17.5 aperture on the 200-inch

form the largest set of homogeneous data presented here. The

range of values of the CO index (0.1 mag) is greater than what

would be expected from the measuring errors alone. This may

indicate a true disperson in the CO index of the sample of

galaxies, or could arise from radial gradients in the CO index

in individual galaxies. The latter effect would influence the

observations because a different fraction of each galaxy is

sampled with a single aperture.

Of the 15 galaxies measured with a 17.5 aperture, six were

also measured with a 59" aperture and two of these were measured

with a 50" aperture. Although there is a tendency for measurements

which include a larger fraction of the galactic radiation to

yield smaller CO indices than those which include a smaller

fraction, the differences are too small, and the number

of galaxies observed is too few, for any significance to be

attached to this trend at the present time. Observations of

these galaxies with apertures between 2 and 3' in diameter are

currently in progress.

Tinsley (1973) has discussed an approach to determining

the evolutionary correction to q_o, the deceleration parameter,

via the strength of the CO bands in giant ellipticals. The data

presented in this paper cannot as yet be used for such a

purpose because of the small aperture sizes used. For example,
in NGC 4486 less than one-third of the light at 2.2 μ is observed
in the 59" aperture and a substantial radial gradient in the
CO index cannot be ruled out until this galaxy is measured
with a larger aperture. If, however, the CO index of this and
other galaxies remains constant with increasing radius, a significant
negative evolutionary correction to q_o is implied (Tinsley 1973).
The present data are probably most useful in complementing
optical data for the construction of stellar synthesis models,
and understanding the evolution of the central regions of elliptical
galaxies (Faber 1972, Rose and Tinsley 1974).

TABLE 1

OBSERVED CO INDICES OF GALAXIES[‡]

GALAXY	TYPE*	PROJECTED APERTURE DIAMETER		
		17"5	50"[†]	59"
NGC 221	E2		0.16 ± 0.02[†]	
NGC 2655	SAB 0/a	0.19 ± 0.01		0.21 ± 0.02
NGC 3379	E1	0.24 ± 0.01		
NGC 3384	SB0	0.24 ± 0.01		
NGC 3607	SA0	0.21 ± 0.01		
NGC 3608	E2	0.22 ± 0.02		
NGC 4278	E1	0.17 ± 0.02		
NGC 4374	E1	0.20 ± 0.02	0.20 ± 0.02	0.18 ± 0.02
NGC 4406	E3	0.22 ± 0.01		0.19 ± 0.01
NGC 4472	E2	0.22 ± 0.01		
NGC 4486	E0p	0.20 ± 0.01	0.16 ± 0.01	0.18 ± 0.01
NGC 4649	E2	0.23 ± 0.01		
NGC 4889	E4	0.14 ± 0.03		
NGC 5846	E0	0.22 ± 0.02		0.19 ± 0.01
NGC 5982	E3	0.16 ± 0.01		0.15 ± 0.05
NGC 6702	E4	0.16 ± 0.03		

‡ The CO index is the $[2.4\mu]$ - $[2.2\mu]$ color in magnitudes, with the CO index of α Lyr defined to be 0.0. The values for NGC 4889 and NGC 6702 have not been corrected for redshift.
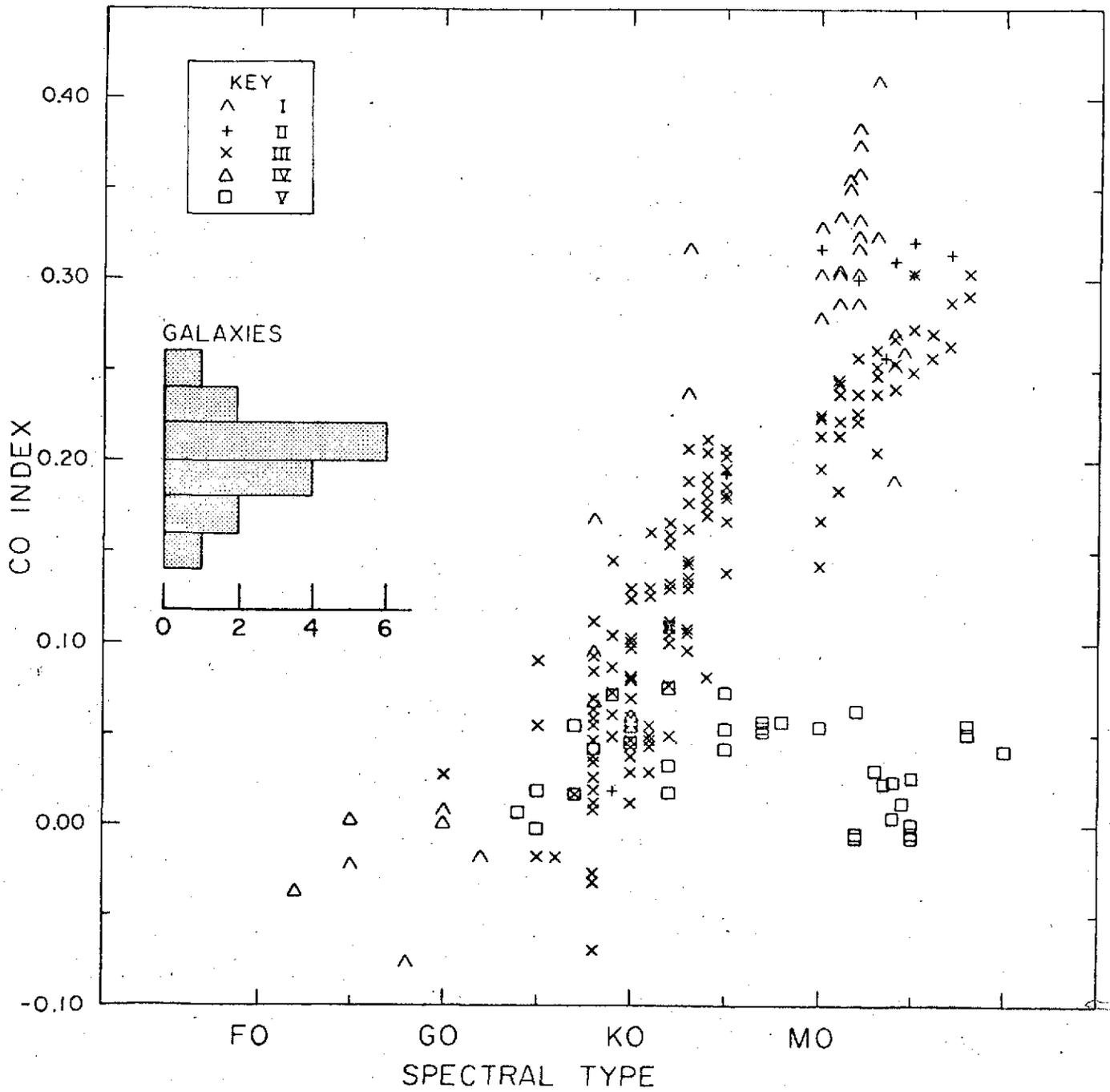
* From de Vaucouleurs and de Vaucouleurs (1964).

† For NGC 221, 1.5-m Mt. Hopkins (40").

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FIGURE CAPTIONS

Fig. 1. – Plot of the CO index ($[2.4\mu]$ – $[2.2\mu]$ color, with the color of α Lyr = 0.0) versus spectral type for stars and galaxies. The galaxy data are grouped into intervals of 0.02 mag, and plotted as a histogram. (Three significant figures were used in drawing the histogram.) Multiaperture data for individual galaxies have been averaged. The CO indices for NGC 6702 and NGC 4889 have been corrected for redshift as discussed in the text.

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