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ABSORPTION LINE GRADIENTS OF AN ELLIPTICAL GALAXY NGC 5322

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ABSTRACT

Archival long-slit spectra, covering the wavelength range 4050 $\sim$ 5150 Å, have been used to investigate the radial behavior of absorption line features (G4300, Fe4383, Ca4455, Fe4531, Fe4668, and Hβ) of an elliptical galaxy NGC 5322. The heliocentric recession velocity of NGC 5322 has been derived as 1888 $\pm$ 51 kms^{-1}. Metallic absorption lines of NGC 5322 show significant radial gradients through the major axis. The minor axis shows much smaller radial metal line gradients than the major axis. The mean slopes of Fe line gradients to the major and minor axes of NGC 5322 were estimated as -0.433 ± 0.064 and -0.242 ± 0.096, respectively. Significant radial gradients of Hβ absorption of NGC 5322 are also detected both on the major and minor axes. It is shown that the radial metallicity gradients in NGC 5322 are smaller than expected in a simple dissipative collapse model. Rather, dissipationless collapse, such as hierarchical merging, could have contributed during the initial stage of the galaxy formation.

1. INTRODUCTION

The study of absorption-line strength gradients in early type galaxies provides the fundamental information for testing models of galaxy formation and evolution. It is now well established that radial stellar population gradients exist in many elliptical galaxies which can be seen in broad band photometry (e.g., Peletier et al. 1990 and refernces therein) and absorption-line strength measurements (e.g., Davies et al. 1993, Gorgas et al. 1990). Larson (1976) argues that dissipative collapse of gas cloud should have a steep radial metallicity gradient, a factor of 10 reduction for a factor of 10 increase of radius. On the other hand, there are indications that radial abundance gradients would be weak if ellipticals formed by dissipationless hierachical merging (e.g., White 1980, Gott 1975). Local environments would also affect the collapse history of elliptical galaxies (e.g., Davidge & Clark 1994).

To date, a few measurements of line strength gradients in elliptical galaxies have been published. In an early study, Faber (1977) measured radial gradients in the Mg_2 index for NGC 4472, two S0 galaxies and the bulge of M31, concluding that all four objects had similar line gradients in agreement with Larson's (1976) dissipative models. More recently, papers by Couture & Hardy (1988), Gorgas et al. (1990), Boroson & Thompson (1991), Faber et al. (1992), Delisle & Hardy (1992), Davidge (1992), Davies et al. (1993), and Davidge & Clark (1994) have reported measurements of line strength gradients in elliptical galaxies. These authors find no strong correlations between the size of the gradient and any other global parameter of the galaxies, such as luminosity or flattening.

It is worth noting that the conclusion that line gradients are primarily driven by radial metallicity gradients is by no means certain. Line indices in galaxies may reflect some complex combination of age and metallicity effects (Burstein et al. 1984, Burstein 1985, Faber et al. 1992, Worthey et al. 1992). Moreover, a calibration between line strength and metallicity is extremly complicated for an unresolved composite stellar population because variations in age and the initial mass function can also produce gradients in the strengths of spectral features (Lee et al. 1999).

In this paper, we report radial absorption line indices (G4300, Fe4383, Ca4455, Fe4531, Fe4668, and Hβ) distributions of NGC 5322 derived from long-slit spectroscopic data. Our measurements of line indices in this particular galaxy NGC 5322 will be able to give observational constraints to the theoretical models of elliptical galaxy formation. NGC 5322 (UGC 8745) is an E4 elliptical galaxy (de Vaucouleurs et al. 1991) with a weak LINER nucleus (Ho et al. 1997). On their UV ($\sim$ 2300Å) images, obtained with the *Hubble Space Telescope (HST)* Faint Object Camera, Maoz et al. (1996) shows weak, diffuse, and centrally concentrated structure that is elongated in the east-west direction, like the major axis of the galaxy in optical images. *HST V*-band images of NGC 5322 (Lauer 1995, Carollo et al. 1997) show a similar structure and also a thin dust lane crossing the nucleus.

2. DATA AND DATA REDUCTIONS

The archival long-slit spectral data of the major and minor axes for NGC 5322, which were obtained during the night of July 21 1991 using the Herzberg spectrograph mounted at the $f/8$ focus of the 3.6m Canada-France-Hawaii Telescope (CFHT) by T.J. Davidge and J.L. Nieto, were retrieved from the CADC (Canadian Astronomy Data Center). The detector was LICK2, a three phase thick Ford Aerospace designed CCD with 15 μm square pixels in a 2048 $\times$ 2048 format. Each pixel subtended 0.63 Å along the dispersion axis and 0.43 arcsec along the slit, which has a projected length of 131 arcsec. The slit was opened to a width of 3 arcsec and was oriented to the major and minor axes of the galaxy. Two 1500 seconds exposures were recorded for each axis. The resolution of the data, as measured from the FWHM of arc lines, is $\sim$ 3.5 Å.

Data reduction consisted of (1) bias subtraction; (2) division by a flat field frame, to correct for pixel-to-pixel variations in detector sensitivity; (3) wavelength calibration, based on observations of a Fe/Ar arc which were recorded following each set of observations; (4) alignment and coaddition of the spectra; and (5) sky subtraction. Sky levels were measured at both ends of the slit with the galaxy placed on the center of the field of view. The final wavelength range of the spectra is 4050 $\sim$ 5150 Å.

One dimensional spectra were then constructed by summing the sky subtracted two dimensional spectra in the spatial direction. Five radial intervals, defined according to the distance from the center of the galaxy, were used to bin the data of the major axis: (1) 0 - 0.64 arcsec; (2) 0.64 - 1.50 arcsec; (3) 1.50 - 3.21 arcsec; (4) 3.21 - 6.63 arcsec; (5) 6.63 - 17.31 arcsec. For the minor axis, the fifth bin was not used to extract a spectrum because of its low signal to noise ratio. One dimensional

Table 1. Spectral indices for NGC 5322 major axis.

Index	$0''.32$	$1''.07$	$2''.36$	$4''.92$	$11''.97$
G4300	5.60 ± 0.06	5.13 ± 0.08	4.76 ± 0.10	4.75 ± 0.12	4.24 ± 0.22
Fe4383	2.49 ± 0.10	2.39 ± 0.12	2.19 ± 0.15	2.15 ± 0.15	1.93 ± 0.23
Ca4455	2.83 ± 0.09	2.68 ± 0.13	2.23 ± 0.13	1.92 ± 0.13	1.50 ± 0.20
Fe4531	2.38 ± 0.08	2.29 ± 0.10	2.11 ± 0.11	1.91 ± 0.12	1.62 ± 0.19
Fe4668	1.76 ± 0.11	1.67 ± 0.13	1.49 ± 0.15	1.33 ± 0.15	1.04 ± 0.28
Hβ	1.78 ± 0.09	1.76 ± 0.12	1.75 ± 0.11	1.42 ± 0.13	1.35 ± 0.25

spectra were corrected for atmospheric extinction using the extinction curve at CFHT published by Beland et al. (1988). The summed spectra were then flattened by a continuum function, which was empirically determined by a polynomial fit. A 6th order function was fitted to the one dimensional spectra of the galaxy.

3. MEASUREMENT OF SPECTRAL FEATURES

Portions of the final binned spectra are shown in Figure 1 and Figure 2. The strengths of various absorption features in the spectra of the major and minor axes of NGC 5322 were measured using the line and continuum positions defined by Worthey et al. (1994). The resulting spectral indices are specified as equivalent widths of G 4300, Fe 4383, Ca 4455, Fe 4531, Fe 4668, and Hβ in Å. An interactive multi-Gaussian fitting task SPLOT in IRAF has been applied to measure equivalent widths and central wavelengths of each line.

The radial velocity of NGC 5322 was estimated from the central wavelengths of each line as $1888 \pm 51\ kms^{-1}$, where the uncertainty is the standard error of central wavelength measurements of each line. This value is in excellent agreement with the recession velocity of NGC 5322, $v_r = 1915 \pm 51\ kms^{-1}$, quoted from RC3 (de Vaucouleurs et al. 1991). The indices measured from the spectra of the major and minor axes of NGC 5322 are listed in Table 1 and Table 2. The uncertainties listed in these tables are standard errors of the mean.

4. ABSORPTION LINE GRADIENTS

The strengths of various absorption features in the major and minor axes of NGC 5322 are plotted as a function of log (radius) in Figure 3 and Figure 4. The unweighted least square fits between the various spectral indices and log(r'') were applied to the data in Table 1 and Table 2 in an effort to determine the amplitude of radial absorption line gradients in NGC 5322. The resulting slopes, $\Delta\mathrm{index}/\Delta \log(r)$, are summarized in Table 3.

It is apparent that the strengths of the metal lines change with radius through the major axis of NGC 5322, in the sense that they become weaker in the outer regions. There are still significant metal line gradients through the minor axis, even though they are much weaker than those of the

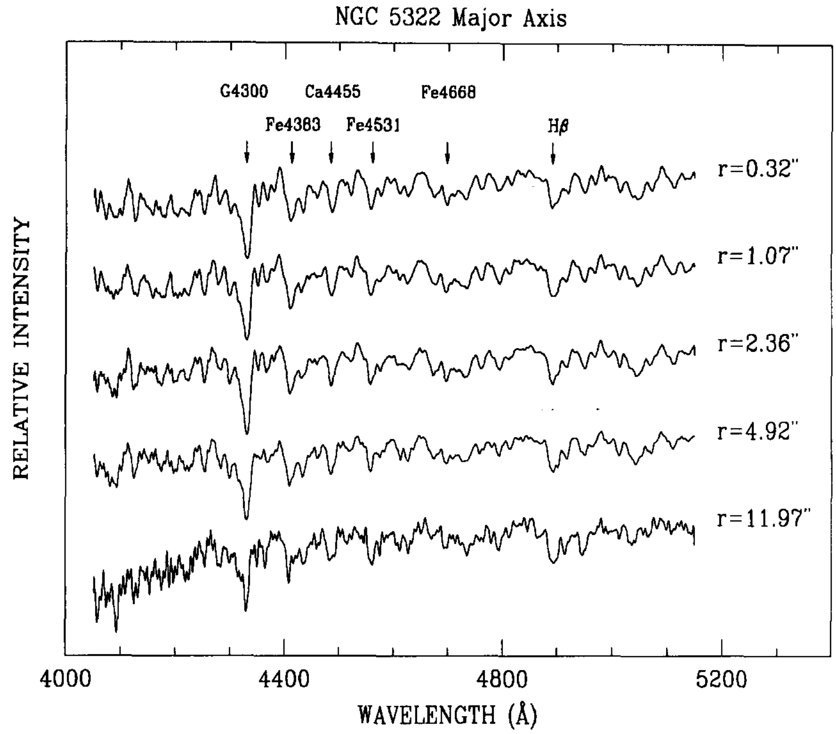

Figure 1. Spectra of NGC 5322 major axis in the wavelength interval 4050 ~ 5150 Å ordered according to the distance from the nucleus. The locations of various features considered in this study are indicated.

major axis. The mean slopes of Fe line gradients of our measurements (Fe4383, Fe4531, Fe4668) to the major and minor axes of NGC 5322 were estimated as -0.433 ± 0.064 and -0.242 ± 0.096, respectively. Line gradients of G band (-0.820 ± 0.090) and Ca4455 (-0.881 ± 0.114) through the major axis are much steeper than those of Fe lines. Hβ absorptions in NGC 5322 also show a significant radial gradient on the major axis (-0.302 ± 0.096). There is still a significant radial gradient of Hβ abosorption through the minor axis of NGC 5322 (-0.474 ± 0.077). Note that Gorgas et al. (1990) found no significant difference between the major and minor axes gradients in Mg_2 or other indices for the three galaxies that they observed along both axes.

The mean Fe line gradient of NGC 5322 in this paper is in good agreement with the mean <Fe> gradient of -0.38 ± 0.26 derived by Davies et al. (1993) for 13 elliptical galaxies and -0.58 ± 0.35 quoted by Gorgas et al. (1990) for a combined sample of elliptical, cD and S0 galaxies. But, it is significantly shallower than the mean of -0.87 ± 0.31 found by Davidge (1992) from long-slit

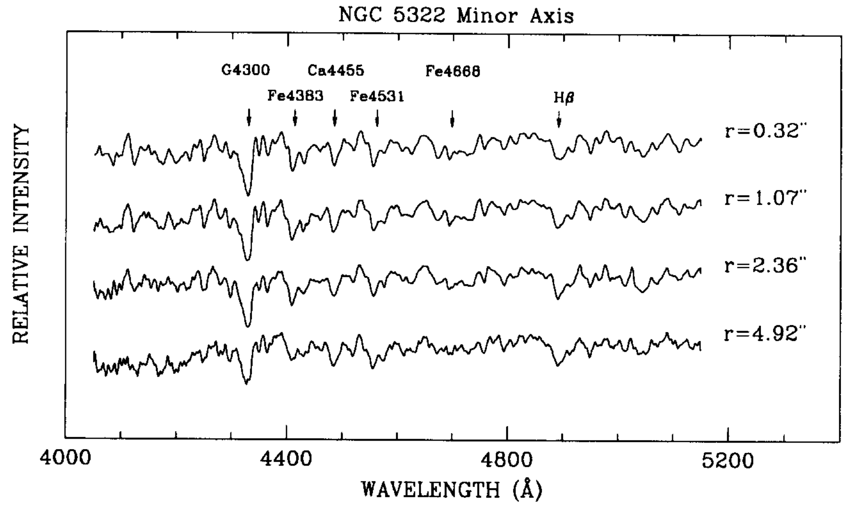

Figure 2. Spectra of NGC 5322 minor axis. Same as Figure 1.

spectra of eleven bright elliptical galaxies. The line gradients of G band and CaII H&K for NGC 5322 are also in good agreements with the previously determined mean values of elliptical galaxies (Davidge & Clark 1994), i.e., ΔCH/Δ log (r)= -0.82 and ΔCaH&K/Δ log (r)= -0.80.

Radial profiles of metal lines would be interpreted in terms of radial variations in mean age and metallicity of stellar populations. If elliptical galaxies form purely by dissipational collapse, then they should have steep abundance gradients (Larson 1976, Carlberg 1984). In theoretical models (e.g., Larson 1976), the shape of the metallicity gradient is fixed by the star formation; steep metallicity gradients are produced if the star formation rate is slower than the time scale for gas to sink in the central region, a factor of 10 reduction for a factor of 10 increase of radius. Conversely, a purely stellar merger origin for elliptical galaxies produces no metallicity gradients. Using the calibration by Faber et al. (1985), and assuming that radial change of Fe lines in NGC 5322 is due to metallicity variation alone, we derive an abundance gradient of -0.22 ± 0.1 in [Fe/H]. This value is in good agreement with the value Δ[Fe/H]/Δlog(r) of -0.21 ± 0.10 derived by Davies et al. (1993), -0.22 ± 0.10 derived from the Mg_2 index by Gorgas et al. (1990), and -0.25 derived by Couture & Hardy (1988). Consequently, the abundance gradient in NGC 5322 is remarkably similar to the values of other elliptical galaxies, and consistent with the result that abundance gradients in elliptical galaxies are rather shallow than those expected on a simple dissipative collapse model (Davies et al. 1993). It should be, however, noted that in the presence of the positive age gradient with radius as inferred from Hβ index, the above estimate for the mean metallicity gradient would be in fact underestimated, due to considerable dependence of metal line strength on population age. It is worth noting here that there are also evidences of broadband color gradients in NGC 5322 in the sense of redder center, which imply stellar populations and metallicity gradients as well. On their multicolor

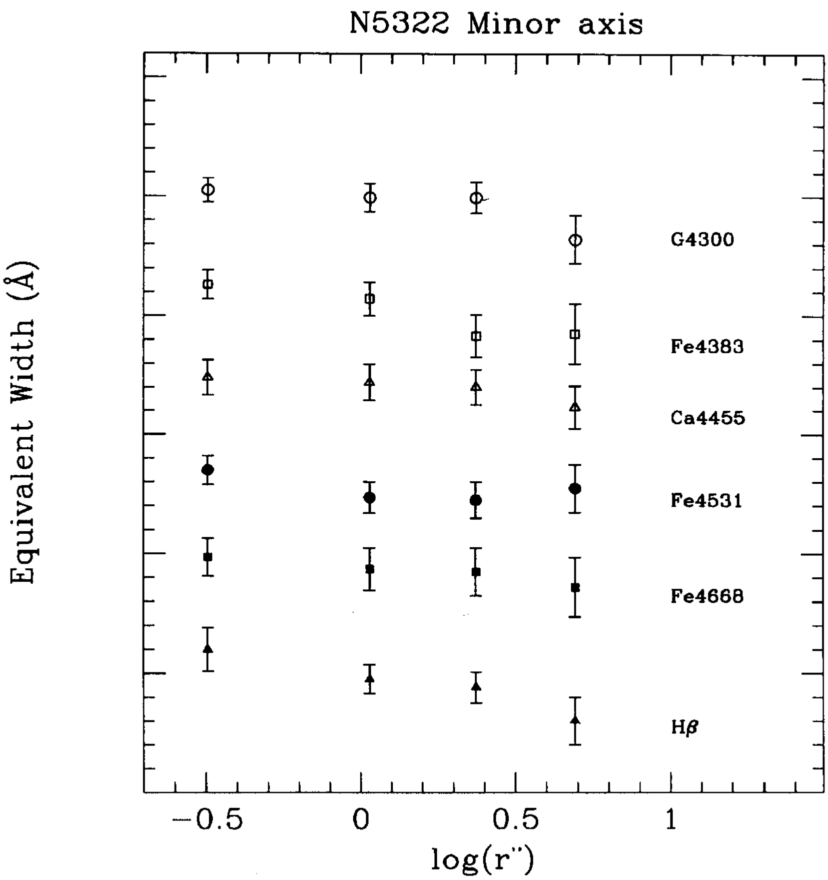

Figure 3. The behavior of various line indices in NGC 5322 major axis as a function of the logarithm of the distance from the center of the galaxy, measured in arcsec.

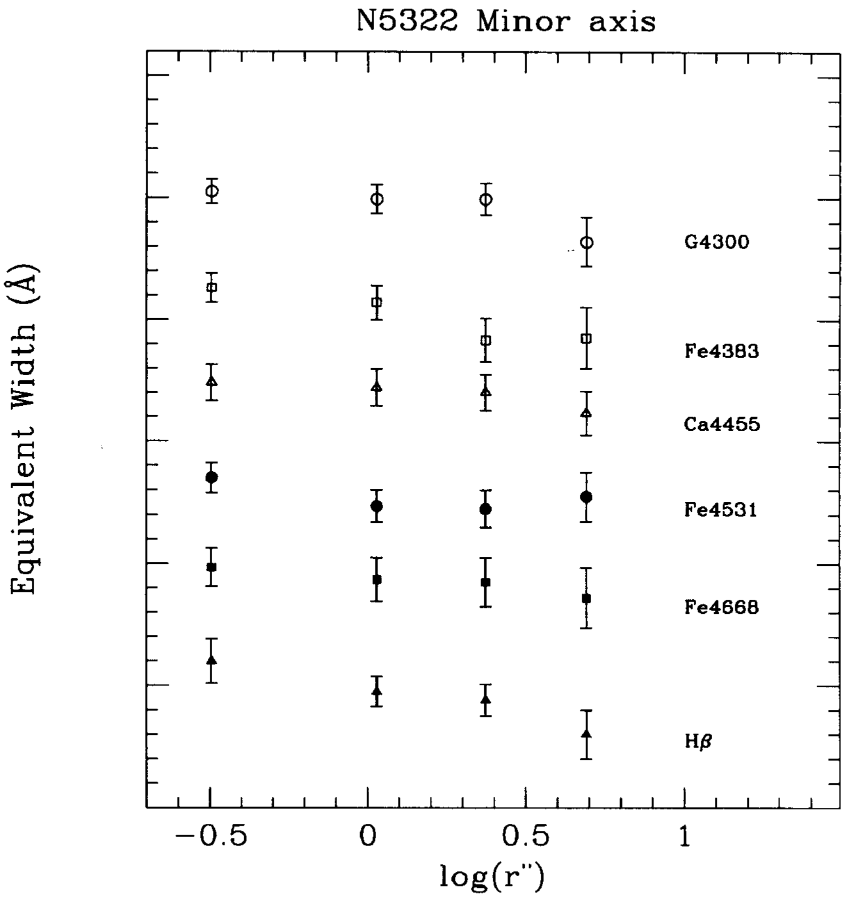

Figure 4. The behavior of various line indices in NGC 5322 minor axis. Same as Figure 3.

Table 2. Spectral indices for NGC 5322 minor axis.

Index	$0''.32$	$1''.07$	$2''.36$	$4''.92$
G4300	5.05 ± 0.10	4.99 ± 0.12	4.99 ± 0.13	4.64 ± 0.20
Fe4383	3.26 ± 0.12	3.14 ± 0.14	2.83 ± 0.18	2.46 ± 0.25
Ca4455	2.48 ± 0.15	2.44 ± 0.15	2.40 ± 0.15	2.23 ± 0.18
Fe4531	2.70 ± 0.12	2.47 ± 0.13	2.45 ± 0.15	2.55 ± 0.20
Fe4668	1.47 ± 0.16	1.37 ± 0.18	1.35 ± 0.20	1.22 ± 0.25
Hβ	2.70 ± 0.18	2.45 ± 0.12	2.38 ± 0.13	2.10 ± 0.20

Table 3. Line gradients, $\Delta\mathrm{index}/\Delta \log(r)$, for NGC 5322 major and minor axes.

Index	major axis	minor axis
G4300	-0.820 ± 0.090	-0.295 ± 0.156
Fe4383	-0.354 ± 0.043	-0.392 ± 0.107
Ca4455	-0.881 ± 0.114	-0.192 ± 0.071
Fe4531	-0.488 ± 0.075	-0.141 ± 0.122
Fe4668	-0.458 ± 0.069	-0.194 ± 0.040
Hβ	-0.302 ± 0.096	-0.474 ± 0.077

CCD surface photometry, Goudfrooij et al. (1994) found that $\Delta(B - V)/\Delta \log(r) = -0.06$ and $\Delta(B - I)/\Delta \log(r) = -0.16$ for the central region of NGC 5322. Carollo et al. (1997) have analyzed the *HST* WFPC2 F555W and F814W (i.e., V and I) images of NGC 5322 and derived that $\Delta(V - I)/\Delta \log(r) = -0.160$ for $r = 0''.25 \sim 1''.5$ and $\Delta(V - I)/\Delta \log(r) = -0.048$ for $r = 1''.5 \sim 10''$ region.

Hβ absorption feature is another key tool to test galaxy formation histories. Davies et al. (1993) showed that Hβ absorption is constant or increase with increasing radius of elliptical galaxies, suggesting that profiles arise at the central region because of the weak emission in the galaxy nuclei. A number of elliptical galaxies have weak emissions in their nuclei and sometimes further out (Phillips et al. 1986, Caldwell 1984). Despite having an evidence of a weak LINER nucleus feature (Ho et al. 1997), however, NGC 5322 still shows significant radial Hβ absorption gradients as above. Moreover, the true equivalent width of the Balmer absorption line in NGC 5322, especially near the nucleus, will be larger than indicated by the measured Hβ line strengths because of its LINER nucleus feature. Note that Gorgas et al. (1990) derived the mean Hβ line gradient of elliptical galxies as -0.34 ± 0.22, which is very simliar to the value of NGC 5322. Davidge (1992) also suggested that there are system-to-system differences in the star formation histories of elliptical galaxies.

Although the interpretation is complex and the measurement is often complicated by emission, the Hβ line strength index has been used as an age indicator (Worthey 1994). Not affected is Hβ of NGC 5322 by emission, then an implication follows from our findings. The Hβ gradient predicts the moderate age gradient, in the sense of younger-looking stellar population in the inner regions relative to the outer parts. This is in favor of dissipationless formation scenario, in which those having denser stellar components formed at late times. A merger origin for elliptical galaxies might account for our observed age gradient if the inflow of accreted gas was followed by star formation at the galaxy center. Note that no strong correlations have been reported between line strength gradients and either photometric or kinematic galaxy parameter for large sample of ellipticals (e.g., Davidge 1992), implying there should be a diversity in star formation histories for elliptical galaxies.

In summary, amounts of radial gradients for metal and Hβ absorption lines lead us to conclude that NGC 5322 was not formed simply through the dissipative collapse. Rather, hierarchical merging and dissipationless collapse must have contributed during the initial stage of the galaxy formation. We caution, however, that the conversion from line strength gradients to abundance and age gradients is not straightforward. The population components sampled along the line of sight may be neither coeval nor uniform metallicity (Davies et al. 1993, Tinsley & Gunn 1976). Therefore, to gain a better understanding of the abundance and age variation and, thus the formation history of NGC 5322, it is necessary to compare the composite spectral synthesis models with high quality spectroscopy over a wide wavelength range. As pointed out by many authors (e.g., Ferguson 1995, Faber et al. 1995) in this field, the effects of warm stellar populations such as horizontal-brach stars and blue stragglers, and of sizable metallicity spreads expected in elliptical galaxies are not fully studied yet, and thus it is obviously needed to construct new population synthesis models.

5. SUMMARY

The archival long-slit spectral data of an elliptical galaxy NGC 5322, covering the wavelength range 4050 $\sim$ 5150 Å, have been retrieved from CFHT archives of CADC. The data have been used to investigate the radial behavior of absorption features of this system. The heliocentric recession velocity of NGC 5322 was derived to be 1888 $\pm$ 51 kms^{-1}. Metal absorption lines of NGC 5322 show significant radial gradients through the major axis, while the minor axis shows much smaller radial metal line gradients than the major axis. Significant radial gradients of Hβ absorption of NGC 5322 are also detected both on the major and minor axes. It is shown that the radial line gradients in NGC 5322 are shallower than expected. From this result it can be concluded that NGC 5322 is not formed simply through dissipative collapse. Rather, hierarchical merging and dissipationless collapse would have contributed during the initial stage of the galaxy formation. Because the stellar population distribution in a galaxy may indicate radial variations in the mean age of the stellar population as well as variations in metallicity, it would be worthwhile to construct composite stellar population and spectral synthesis models to interpret the radial absorption line gradients in NGC 5322.

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REFERENCES

Beland, S., Boulade, O., & Davidge, T. J. 1988, CFHT Info. Bull. 19, 16
Boronson, T. A. & Thompson, I.B. 1991, AJ, 101, 111
Burstein, D. 1985, PASP, 97, 89
Burstein, D., Faber, S. M., Gaskell, C. M., & Krumm, N. 1984, ApJ, 287, 586
Caldwell, N. 1984, PASP, 96, 287
Carlberg, R. G. 1984, ApJ, 286, 403
Carollo, C. M., Franx, M., Illingworth, G. D., & Forbes, D. A. 1997, ApJ, 481, 710
Couture, J. & Hardy, E. 1988, AJ, 96, 867
Davidge, T. J. 1992, AJ, 103, 1512
Davidge, T. J. & Clark, C. C. 1994, AJ, 107, 946
Davies, R. L., Sadler, E. M., & Peletier, R. F. 1993, MNRAS, 262, 650
Delisle, S. & Hardy, E. 1992, AJ, 103, 711
de Vaucouleurs, G., de Vaucouleurs, A. Corwin, H. G., Buta, R. J., Paturel, G, & Fouque, P. 1991, Third Reference Catalog of Bright Galaxies (New York: Springer)
Faber, S. M. 1977, The Evolution of Galaxies and Stellar Populations (New Haven, Yale University Press), 157
Faber, S. M., Friel, E. D., Burstein, D. & Gaskell, C. M. 1985, ApJS, 57, 711
Faber, S. M., Trager, S. C., Gonzalez, J. J. & Worthey, G. 1995, in IAU Symp. 164, Stellar Populations, ed. P. C. van der Kruit & G. Gilmore (Dordrecht:Kluwer), 249
Faber, S. M., Worthey, G., & Gonzalez, J. J. 1992, IAU Symp. 149, The Stellar Populations of Galaxies (Dordrecht, Kluwer), 255
Ferguson, H. C. 1995, in IAU Symp. 164, Stellar Populations, ed. P. C. van der Kruit & G. Gilmore (Dordrecht:Kluwer), 239
Gorgas, J., Efstathiou, G., & Salamanca, A. A. 1990, MNRAS, 245, 217
Gott, J. R. 1975, ApJ, 201, 269
Goudfrooij, P., Hansen, L., Jorgensen, H. E., Norgaard-Nielsen, H. U., de Jong, T., & van den Hoek, L. B. 1994, A&AS, 104, 179
Ho, L. C., Filippenko, A. V., & Sargent, W. W. 1997, ApJ, 487, 579
Larson, R. B. 1976, MNRAS, 176, 31
Lauer, T. R. 1995, AJ, 110, 2622
Lee, Y. W., Lee, H. C., & Yoon, S. J. 1999, BAAS, 30
Maoz, D., Filippenko, A. V., Ho, L. C., Macchetto, D., Rix, H. W., & Schneider, D. P. 1996, ApJS, 107, 215
Peletier, R. F., Davies, R. L., Illingworth, G. D., Davis, L. E., & Cawson, M. 1990, AJ, 100, 1091
Phillips, M. M., Kenkins, C. R., Dopita, M. A., Sadler, E. M. & Binnette, L. 1986, AJ, 90, 1061
Tinsley, B. M. & Gunn, J. E. 1976, ApJ, 206, 525
White, S. D. M. 1980, MNRAS, 253, 710
Worthey, G. 1994, ApJS, 95, 107
Worthey, G., Faber, S. M., Gonzalez, J. J., & Burstein, D. 1994, ApJS, 94, 687
Worthey, G., Faber, S. M., & Gonzalez, J. J. 1992, ApJ, 398, 69