RevMexAA (Serie de Conferencias), **16**, 103–107 (2003)

LINE STRENGTH MAPPING OF THE STELLAR POPULATIONS WITHIN ELLIPTICAL GALAXIES

A. Vazdekis,[1] J. J. González,[2] L. Olguín,[2] J. Gorgas,[3] J. Cenarro,[3] N. Cardiel,[3] P. Sánchez-Blázquez,[3] and S. Pedraz[3]

RESUMEN

Debido a la importancia de los gradientes de líneas de absorción en el estudio de la formación y evolución secular de las galaxias elípticas, se propone obtener mapas de intensidad de líneas de absorción en galaxias elípticas cercanas haciendo uso de OSIRIS y el GTC. Los métodos para observar e interpretar estos mapas están guiados y optimizados mediante sofisticados modelos de síntesis de poblaciones estelares, los cuales permitirán derivar los parámetros característicos de las poblaciones estelares como son las metalicidades, edades, abundancias relativas de elementos y la Función Inicial de Masas. Nuestro principal objetivo es acotar los escenarios de formación y evolución de las galaxias elípticas mediante la información obtenida a partir de la distribución global y radial de sus poblaciones estelares.

ABSTRACT

Given the relevance of line strength gradients to study the formation and secular evolution of elliptical galaxies, we propose to measure deep line strength maps of nearby ellipticals with OSIRIS on the GTC. The methods of observing and interpreting these maps are guided and optimized on the basis of highly specialized and sophisticated synthesis models and will be used to derive relevant parameters of the integrated population, such as stellar metallicities, ages, abundance ratios, and the initial mass function. Our main goal is to provide further and stronger constraints on the formation and evolution scenarios of elliptical galaxies on the basis of the information provided by the global and radial distribution of their stellar populations.

Key Words: **GALAXIES: ABUNDANCES — GALAXIES: ELLIPTICAL AND LENTICULAR, CD — GALAXIES: EVOLUTION — GALAXIES: FORMATION — GALAXIES: STELLAR CONTENT**

1. INTRODUCTION

1.1. *Stellar populations and galaxy formation scenarios*

Two main competing galaxy formation scenarios have been proposed: elliptical galaxies (Es) either form monolithically by gravitational collapse with energy dissipation (Eggen, Lynden-Bell & Sandage 1962; Larson 1974; Arimoto & Yoshii 1987), or within a hierarchical galaxy formation framework, in which the smaller galaxies merge to build up larger ones (Toomre & Toomre 1972; Cole et al. 1994; Kauffmann & Charlot 1998). In the first scenario Es constitute a uniform class of objects, with global properties changing gently with mass and hosting old and coeval stellar populations. Conversely, a wider range of star formation histories is expected in the second scenario. Since the stellar populations constitute a fossil record of the star formation and chemical evolution histories of the elliptical galaxies, analysis of their colors and spectroscopic absorption features should help us in constraining the relative importance of these scenarios.

Stellar population studies of galaxy centers have not provided us with a clear picture. The tight relations followed by the elliptical family, such as the fundamental plane (Djorgovsky & Davis 1987), the color–magnitude relation (CMR) (Bower, Lucey & Ellis 1992) and the Mg_2–σ relation (Colless et al. 1999) seem to indicate that Es formed at very high redshift, apparently favoring the monolithic scenario, although hierarchical galaxy formation models can be tuned up to satisfy these relations as well. While recent line strength-based studies have shown that Es are mainly old—particularly those in clusters (e.g., Terlevich et al. 1999; Kuntschner 2000; Vazdekis et al. 2001a), other authors (González 1993; Jørgensen 1999; Trager et al. 2000) find a significant intermediate-age population in some Es. These conclusions are still subject to local processes that may be occurring at the center and do not necessarily apply to the galaxies as a whole (González & Gorgas 1996).

[1]Instituto de Astrofísica de Canarias, Spain.
[2]Instituto de Astronomía, UNAM, Mexico.
[3]Universidad Complutense de Madrid, UCM, Spain.

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

Under a dissipational collapse scenario, steep negative metallicity gradients are expected, as well as a trend towards stronger gradients with increasing galaxy mass and central metallicity (Carlberg 1984). Models based on successive mergers of smaller galaxies would extent the star formation, mostly in the central parts of a galaxy, predicting flatter gradients of common metallicity indicators (such as Mg_2). Therefore, line strength gradients constitute a quantitative diagnostic of the amount of dissipation during galaxy formation and further the model constraints.

1.2. *Line strength gradient determinations*

In the last decade spectral gradients of only a few features have been studied (Gorgas, Efstathiou & Salamanca 1990; González 1993; Davies, Sadler & Peletier 1993; Carollo, Danziger & Buson 1993; Fisher, Franx & Illingworth 1995; González & Gorgas 1996; Kobayashi & Arimoto 1999); typically, such gradients do not reach beyond one effective radius. These studies have shown that Mg and Fe line strengths decline outwards. However, gradients seem shallower than predicted by dissipational collapse models, probably because of merger effects (White 1980). González & Gorgas (1996) found that bright Es show steeper gradients than fainter ones, but their gradients cross over around an effective radius, suggesting that global metallicity among Es differs much less than inferred from their central line strengths. This result has an important impact on the global relations of Es, mostly studied from observations of the central parts of galaxies. It could be argued that the CMR for galaxy centers may not well reflect the E formation process, and that a more global CMR or related relations (such Mg_2–σ) are flatter than previously inferred (González & Gorgas 1996). However, this is yet to be confirmed and needs to studied further.

Fisher, Franx & Illingworth (1995) found flat Hβ gradients in brightest cluster members and declining Mg gradients, suggesting that their centers are around 1–3 Gyr younger than their outer regions, most probably as a result of more recent or more extended star formation. On the other hand, fitting simultaneously a large number of spectral features and colors, Vazdekis et al. (1997) find metallicity to be the main parameter driving the gradients of three well known early-type galaxies. Being so hard to measure, no clear age or relative abundance gradients have yet been unambiguously detected.

Although Es define a correlation between Mg_2 gradient and σ_0 (e.g., Peletier 1989; Gorgas, Efstathiou & Salamanca 1990; Davidge 1992), a large scatter is present (González 1993; Davies, Sadler & Peletier 1993), and cD galaxies deviate considerably (Carollo, Danziger & Buson 1993). However, a better correlation is found with the central Mg_2 (González & Gorgas 1996). A robust link is also found between local colors and local line strengths, and both correlate tightly with local escape velocity (Franx & Illingworth 1990; Davies, Sadler & Peletier 1993). (González & Gorgas 1996) suggest that the mean age of the stellar populations could be driving the diversity of Hβ strengths among Es and the scatter in the Mg_2–σ relation.

2. OBTAINING RELEVANT STELLAR POPULATION PARAMETERS

Stellar population synthesis models are used to translate measured line strengths and colors to relevant stellar population parameters such as mean luminosity-weighted ages and metallicities. Although less affected than colors, line strengths are not free from age–metallicity degeneracy (Worthey 1994). For example, the Hβ age indicator shows a non-negligible metallicity dependence (Worthey 1994). Moreover, when Hβ is plotted against Mg, the inferred ages are smaller than when plotted versus Fe indices for galaxies with [Mg/Fe] > 0 (Kuntschner 2000; Vazdekis et al. 2001a). The filling up of Hβ by nebular emission is an additional complication, yielding greater ages (Davies, Sadler & Peletier 1993; González 1993). The degeneracy is also due in part to the limitations of the analysis performed at low spectral resolution (FWHM $\sim$ 9Å) and on the basis of preliminary semi-empirical stellar population synthesis models (Worthey 1994; Vazdekis et al. 1996).

Recently, we were able to model full spectral energy distributions for stellar populations at the superb resolution FWHM = 1.8Å (Vazdekis 1999), allowing analysis of spectra at the dynamical resolution of each galaxy (as defined by its own σ). The models allowed us to define a new age indicator, centered on Hγ, completely insensitive to metallicity (Vazdekis & Arimoto 1999; Vazdekis et al. 2001b). These models have been extended to cover the near-IR Ca II triplet feature on the basis of an extensive empirical stellar library (Cenarro et al. 2001a; Cenarro et al. 2001b). The Ca II triplet showed a large sensitivity to the initial mass function (IMF) slope (Cenarro et al. 2002; Vazdekis et al. 2002).

We are currently developing a new generation of stellar population synthesis models and methods for breaking the fundamental degeneracies affecting the stellar populations to fully exploit the OSIRIS + GTC data. Among the improved ingredients of these models we have obtained a new stellar library with an unprecedented coverage of atmospheric parameters. This library, which has been observed on the 2.5 m Isaac Newton Telescope (La Palma), is composed of ∼1100 stars and covers the spectral range $\lambda\lambda$ 3500–7500 Å. Using these models we are defining a number of key indicators and diagnostic diagrams to more accurately disentangle age, metallicity, abundance ratios, and IMF in an oldish stellar population.

3. LINE STRENGTH GRADIENTS AND LINE STRENGTH MAPPING WITH OSIRIS

OSIRIS offers us the possibility to achieve line strength gradients and line strength maps up to galactocentric distances not attainable with current 4 m class telescopes. The strategy to observe extended nearby elliptical galaxies includes long slit (LS) spectroscopy to obtain very deep line strength gradients of a large set of spectral indices, and tunable filter (TF) imaging in charge-shuffled continuum subtraction mode to obtain full two-dimensional line strength maps of selected key spectral features. This approach allows us to reach $\mu_B \sim 23.5$ mag arcsec^{-2} (i.e., 2.5–3 $r_{\rm e}$), achieving S/N (per Å per *arcsec*) $\geq$ 10 by using the LS mode in the blue. With the TFs, we will gain an additional magnitude ($\sim \mu_B \sim 24.5$ mag arcsec^{-2}). The usefulness of the two-dimensional absorption line strength maps for the analysis of the stellar populations have been proved by Emsellem et al. (1996), Peletier et al. (1999), and del Burgo et al. 2001. However, these studies were limited to the innermost galaxy regions. Apart of obtaining line strength gradients, our TF-based absorption feature maps will allow us to find two-dimensional stellar population structures, such as young disks and remnants of mergers, or the distribution of star formation within the area covered, i.e., 3-4 $r_{\rm e}$.

Since in the central regions of these galaxies we will achieve spectra of extraordinarily high SN, we will be able to analyze stellar populations through newly defined indices with an uprecedented ability to disentangle the age–metallicity degeneracy, including the Hγ_σ age indicator of (Vazdekis & Arimoto 1999), which cannot be used in the outer parts because of its high SN requirements (SN(Å) $>$ 150). We have estimated that this unambiguous analysis can be performed up to $r_{\rm e}/3$ if we integrate in the spatial dirección to achieve the required SN. This approach provides us very accurate [Mg/Fe] abundance trends (as well as other element ratios), and galaxy mean metallicities (e.g., see Vazdekis et al. 2001a). We further our capability to interpret the stellar population parameters of the outer regions by using the results obtained from the central regions. In this way we can increase the age–metallicity disentangling power of diagnostics relying on, for example, other Balmer lines or other Balmer index definitions, which provide more degenerate age–metallicity diagrams, but which require much lower SN. Our method provides fully calibrated line strengths, within the galaxy system, up to the outer parts of the galaxies. Moreover, the LS line strengths will be used to extend this calibration to the TF indices to obtain fully calibrated two-dimensional line strength maps, reaching even greater galactocentric distances.

To exploit the capabilities of TFs for analyzing absorption features we have started an exhaustive program to identify those spectral features suitable for use in this observing mode. For this purpose we make use of theoretical spectra of stellar populations with different ages and metallicities at resolution FWHM ∼ 2Å provided by our stellar population synthesis model. By convolving the responses of the TF filter with different central wavelengths and FWHM we optimize the TF index definition in terms of increasing its ability to disentangle, for example, ages and metallicities. Moreover, we analyze the stability of the new TF index against shifts in wavelength (e.g., rotation curve) and velocity dispersion of the galaxy. Very similar simulations are performed to quantify the phase effect. The index is also tested against the SN. Our purpose is to build up a well-defined and characterized system of TF-based indices for disentangling accurately the main parameters of the stellar populations.

4. CONCLUSIONS

Absorption line strength gradients of elliptical galaxies represent a very relevant astronomical observation to pursue because:

1. They are a fossil and a live record of E formation history as a result of the amount, speed and halt time of the dissipation process, and the relative effects of mergers and interaction during and after galaxy formation.

2. They are further modified by—and are a measure of—plausible cooling flows of the hot X-ray gas, and the way the acquired gas may settle and form stars.

3. Integrated, the stellar population parameters (mean stellar abundances, SF age, etc.) of the whole galaxy provide us with: *a)* a fair comparison among giant and dwarf Es; *b)* a

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

way to reduce bias toward central properties when deriving and studying important relations such as the color–magnitude relation, the mass–metallicity–age relation, and all derivatives of the fundamental plane of Es; *c)* a more consistent comparison of global properties of nearby, more resolved, galaxies with high redshift—less resolved—galaxies; and *d)* an indicator of galaxy chemical enrichment history, as measured by the abundances of the accumulated living stellar population.

4. They are needed to match the abundance profiles measured in the X-ray haloes around some massive Es.

5. For their reliable measurement, they are coupled to maps of the stellar kinematics, from which galaxy mass can be derived, and provide further and independent clues of the formation and evolution process.

We therefore propose a long term observing program to determine accurate line strength maps of Es beyond their effective radii. For this purpose we combine the long slit and TF observing modes of OSIRIS. Measuring of TF-optimized line strengths, coupled to our associated synthesis modeling, constitutes a uniquely powerful approach for tackling at least the following objectives:

- Study the main gradient trends with galaxy mass among Es.
- Obtain extensive line strength maps in galaxies with different kinematical, dynamical, or photometric properties, to investigate general behavior of the stellar populations in normal and peculiar Es.
- Extend line strength studies to a larger number of features and investigate how the gradients of the population indicators behave and correlate.
- Establish robust correlations (and effects) of gradients and abundance trends with the main galaxy E scaling relations.
- Study the role played by the mean stellar age in the observed gradients. Balmer indices will be measured, as well as TF-optimized indices to break age–metallicity degeneracies.
- Derive and study the main parameters of the stellar populations of Es.

Our main goal is to provide further and stronger constraints on galaxy formation and evolution scenarios based on the information provided by the global and radial distribution of their stellar populations.

REFERENCES

Arimoto, N., & Yoshii, Y. 1987, A&A, 173, 23

Bower, R. G., Lucey, J. R., & Ellis, R. S. 1992, MNRAS, 254, 601

Carlberg, R. 1984, ApJ, 286, 403

Carollo, C., Danziger, I., & Buson, L., 1993, MNRAS, 265, 553

Cenarro, A. J., Cardiel, N., Gorgas, J., Peletier, R. F., Vazdekis, A., & Prada, F. 2001a, MNRAS, 326, 959

Cenarro, A. J., Gorgas, J., Cardiel, N., Pedraz, S., Peletier, R. F., & Vazdekis, A. 2001b, MNRAS, 326, 981

Cenarro, A. J., Gorgas, J., Cardiel, N., Vazdekis, A., & Peletier, R. F. 2002, MNRAS, 329, 863

Cole, S., Aragon-Salamanca, A., Frenk, C. S., Navarro, J. F., & Zepf, S. E. 1994, MNRAS, 271, 781

Colless, M., Burstein, D., Davies, R. L., McMahan, R., Saglia, R., & Wegner, G. 1999, MNRAS, 303, 813

Davidge, T. 1992, AJ, 103, 1512

Davies, R. L., Sadler, E. M., & Peletier, R. F. 1993, MNRAS, 262, 650

del Burgo, C., Peletier, R., Vazdekis, A., Arribas, S., & Mediavilla, E. 2001, MNRAS, 321, 227

Djorgovsky, S., & Davis, M. 1987, ApJ, 313, 59

Eggen, O., Lynden-Bell, D., & Sandage, A. R. 1962, ApJ, 136, 748

Emsellem, E., Bacon, R., Monnet, G., & Poulain, P. 1996, A&A, 312, 777

Fisher, D., Franx, M., & Illingworth, G. 1995, ApJ, 448, 119

Franx, M., & Illingworth, G. 1990, ApJ, 359, L41

González, J. J. 1993, PhD Thesis, Univ. California, Santa Cruz

González, J. J., & Gorgas, J. 1996, ASP Conf. Ser., 86, Fresh Views of Elliptical Galaxies, ed. A. Buzzoni, A. Renzini, & A. Serrano (San Francisco: ASP), 225

Gorgas, J., Efstathiou, G., & Salamanca, A. 1990, MNRAS, 245, 217

Jørgensen, I. 1999, MNRAS, 306, 607

Kauffmann, G., & Charlot, S. 1998, MNRAS, 297, L23

Kobayashi, C., & Arimoto, N. 1999, ApJ, 527, 573

Kuntschner, H. 2000, MNRAS, 315, 184

Larson, R. B. 1974, MNRAS, 166, 585

Peletier, R., Vazdekis, A., Arribas, S., del Burgo, C., García-Lorenzo, B., Gutiérrez, C., Mediavilla, E., & Prada, F. 1999, MNRAS, 310, 863

Peletier, R. 1989, PhD Thesis, Univ. Groningen

Terlevich, A., Kuntschner, H., Bower, R. G., Caldwell, N., & Sharples, R. 1999, MNRAS, 310, 445

Toomre, A., & Toomre, J. 1972, ApJ, 178, 623

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

Trager, S., Faber, S., Worthey, G., & González, J. 2000, AJ, 120, 165
Vazdekis, A., Casuso, E., Peletier, R. F., & Beckman, J. E. 1996, ApJS, 106, 307
Vazdekis, A., Peletier, R. F., Beckman, J. E., & Casuso, E. 1997, ApJS, 111, 203
Vazdekis, A. 1999, ApJ, 513, 224
Vazdekis, A., & Arimoto, N. 1999, ApJ, 525, 144
Vazdekis, A., Kuntschner, H., Davies, R., Arimoto,N., Nakamura, O., & Peletier,R. 2001a, ApJ, 551, L127
Vazdekis, A., Salaris, M., Arimoto, N., & Rose, J. 2001b, ApJ, 549, 274
Vazdekis, A., Cenarro A. J., Gorgas J., Cardiel, N., Peletier R. F. 2002, MNRAS, in preparation
White, S. D. M. 1980, MNRAS, 191, 1
Worthey, G. 1994, ApJS, 95, 107

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
Editors: José Miguel Rodríguez Espinosa, Francisco Garzón López & Verónica Melo Martín

A. Vazdekis: Instituto de Astrofísica de Canarias, IAC, E-38205 La Laguna, Tenerife, Spain (vazdekis@ll.iac.es)
J. J. González and L. Olguín: Instituto de Astronomía, UNAM, Apdo. Postal 70-264, 04510 México D.F., Mexico
J. Gorgas, J. Cenarro, N. Cardiel, P. Sánchez-Blázquez and S. Pedraz: Departamento de Astrofísica, Facultad de Físicas, Universidad Complutense, E-28040 Madrid, Spain