Publ. Astron. Obs. Belgrade No. 67 (2000), 73 – 80 *Invited lecture*

THE LOCAL $\mathrm{Mg_2} - \log\sigma$ RELATION FOR EARLY-TYPE GALAXIES THROUGH THE DATABASE HYPERCAT

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Abstract. We report the local $\mathrm{Mg_2}(r)$ vs. $\log\sigma(r)$ relationship of 9 typical elliptical and 9 typical S0 galaxies whose data are maintained in the extragalactic database *HYPERCAT*. The two relations, for E and S0 galaxies, are significantly different. The contribution of the rotation to the local potential at the time of star formation bulk could provide an explanation of this difference. The analysis shows that the appropriate accounting for the rotational support is conductive to the $\mathrm{Mg_2}(r) - \log\sigma(r)$ relation for S0s becoming like that for the ellipticals. This would mean that the disks of S0s are both old and have a high metallicity. Thus, the qualitative difference between the local $\mathrm{Mg_2}(r) - \log\sigma(r)$ relationship of S0s and ellipticals may still be compatible with a model of dissipative quasi-simultaneous formation of the disk and the bulge.

1. INTRODUCTION

The $\mathrm{Mg_2}$ absorption line-strength index is a measure of one of the most prominent features in the optical spectra of early-type galaxies. It is one of the dozen well-known line-strength indices that are successfully used to study the old stellar populations in early-type galaxies (see e.g. González 1993 and references therein).

It is also well established that the correlation between central $\mathrm{Mg_2}$ absorption line-strength index and the central velocity dispersion σ_0 of dynamically hot stellar systems is very tight (Dressler et al. 1987; Burstein et al. 1988; Bender et al. 1993). Although these systems comprise four orders of magnitudes in mass and luminosity (ranging from the bulges of spirals and S0s up to the giant ellipticals) and their $\mathrm{Mg_2}$ indices differ by up to $0\overset{m}{.}35$, the scatter of $\mathrm{Mg_2} - \log\sigma_0$ relation remains low (Ziegler & Bender 1997). The relationship between the central $\mathrm{Mg_2}$ index and the central velocity dispersion σ_0 connects one dynamical parameter and another one that arises entirely through the physics of stellar evolution, thus suggesting a remarkably close connection between the chemical and dynamical evolution of early-type galaxies (Davies 1995; González & Gorgas 1995).

On the third hand, early-type galaxies exhibit systematic variations in the line-strength indices going from the center to the external galaxy regions (cf. González 1993; Fisher et al. 1995, 1996). This suggests the change in some fundamental properties of the constituent stellar population of these galaxies. Either the age or the metallicity of the stellar content (or both reasons simultaneously) could probably be responsible for the index variations.

In this report we will focus on the local $\mathrm{Mg}_2(r)-\log\sigma(r)$ relationship of some bona-fide elliptical and S0 galaxies. This work is part of a long-term project dedicated to the study of the scaling relations of early-type galaxies (see Prugniel & Simien 1994, 1996, 1997, and Prugniel et al. 1999) connected with the Lyon's extragalactic database *HYPERCAT* (Prugniel & Golev 1999; Maubon et al. 1999)

2. THE HYPERCAT PROJECT

The *HYPERCAT* database is a collaboration initiated at Observatoire de Lyon, France, involving the University of Sofia, Bulgaria, the Sternberg Institute in Moscow, Russia, and two Italian observatories: Brera in Milano and Capodimonte in Napoli.

The aims of Hypercat project are:

Construct, maintain and interface catalogues of galaxies useful for studying their physics. The data catalogued in *HYPERCAT* complement those available through the major extragalactic databases (NED and LEDA). Links to these data bases and to ADS and SIMBAD are provided for each object or reference. DSS images of the object may also be obtained through the *HYPERCAT* interface. Elaborate data-mining utilities and developed pipelines to extract astrophysical parameters are provided. The first step yet accomplished was assembling of FITS archive (HFA) and link its linking analysis pipelines.

HYPERCAT is a tool designed to support our work on the scaling relation of galaxies, but, being available on the Web, it is also used for other purposes. In particular, it can be a useful auxiliary in the preparation of observations, through its capabilities to select and define a sample. A unique characteristic of *HYPERCAT* is that it is jointly operated at different sites: the catalogues, as well as the FITS archive, are maintained separately in different sites and are daily mirrored to Lyon to update the database. In turn, the database is mirrored to the public *HYPERCAT* sites:

`http://www-obs.univ-lyon1.fr/hypercat/` – the main site in Lyon;
`http://astro.uni-sofia.bg/hypercat/` – mirror in Sofia;
`http://palladio.brera.mi.astro.it/hypercat/` – mirror in Milan;
`http://www.na.astro.it/hypercat/` – mirror in Napoli.

This organization is quite complex, as it involves about 10 computers, but is efficient since it minimizes the need of non- automatic interactions for the operations of database management. It also exerts a heavy pressure on the network, but since all communications are concentrated during the low- traffic hours the network capacity is sufficient. Note however that having distributed mirrors of the database also reduces the long-distance network load during the heavy-traffic hours.

The HFA itself is structured in datasets, each corresponding to a set of observations taken in the same conditions.

Together with the science frames, all other information necessary to the data reduction is also stored in HFA. They are in particular:

(i) Template objects used for flux calibration.

(ii) Spectra of reference lamp for wavelength calibration.

(iii) Mean flat field (and bias) used in the reduction of science frames.

This structure of the database was used to perform the investigation described below.

2. 1. THE SPECTROSCOPIC DATA

More than 200 spectra of 87 early-type galaxies (S0a and ellipticals between E0 and E4) centered around the Mg*b* λ5175 Å triplet and covering a range of 900 Å have been collected using the 1.93m telescope of the Observatoire de Haute-Provence and the *CARELEC* long-slit spectrograph[1] (Prugniel et al. 1992). The FWHM spectral resolution of 3.2 Å was used. This material is already described in details in Prugniel & Simien (1994) and Simien & Prugniel (1997a, 1997b and 1997c) where the internal kinematics of the sample galaxies is analyzed.

The sample galaxies span a wide range of intrinsic luminosity ($-22^m_{\cdot}0 \lesssim M_B \lesssim -17^m_{\cdot}5$), central velocity dispersion ($70 \lesssim \sigma_0 \lesssim 330$ km s^{-1}), and, as a consequence, of metallicity.

We have already used this spectral archive to derive the central values of Mg_2-index for all 87 early-type objects in the archive (Golev et al. 1999). The central Mg_2 measurements were reduced to the homogeneous, standard Lick system following the procedures described in Golev & Prugniel (1998). A catalog of these measurements together with practically all central Mg_2 measurements available in the literature, converted to the Lick system, can be found in *HYPERCAT*.

Now we have used this spectral archive to derive Mg_2-index radial profiles for 9 typical *bona-fide* elliptical galaxies and 9 typical lenticulars. The individual Mg_2-index profiles were obtained for position angles corresponding to the major axis of each galaxy.

3. THE $Mg_2 - \log\sigma$ RELATIONSHIP

3. 1. THE $Mg_2 - \log\sigma$ DIAGRAM FOR CENTRAL VALUES

We have constructed the Mg_2 vs. $\log\sigma_0$ diagram for a sample of 308 bona-fide elliptical galaxies whose data are maintained in HYPERCAT. The relationship derived

$$Mg_2 = 0.225\,(\pm\,0.009)\log\sigma_0 - 0.238\,(\pm\,0.022) \qquad (1)$$

is the best straight-line fit to data with errors in both Mg_2 and $\log\sigma_0$. This diagram is shown in Fig. 1.

If errors in Mg_2 only were taken into account (which is the usual way to derive this relation), the relationship would be $Mg_2 = 0.181\log\sigma_0 - 0.130$, or, within the errors, *exactly* the classical relation published first by Dressler et al. (1987) and discussed in details by Bender et al. (1993).

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[1] Details on the *CARELEC* long-slit spectrograph and its detectors, as well as the information about the 1.93m telescope itself, are available on the WWW at http://www.obs-hp.fr.

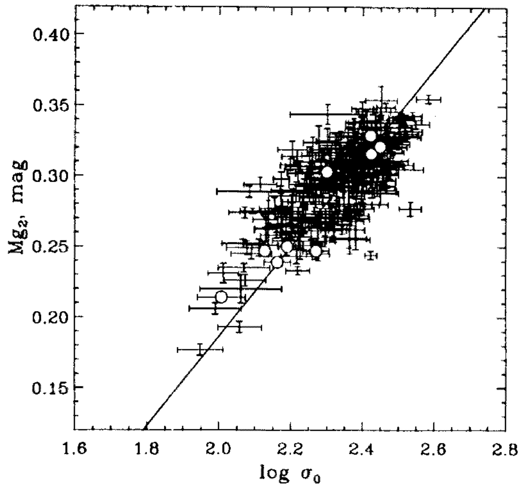

Fig. 1. The relationship between the central Mg_2index and the central velocity dispersionσ_0 for 271 bona-fide elliptical galaxies in HYPERCAT. The solid line represents the best straight-line fit to data with errors in both Mg_2 and $\log \sigma_0$. Open circles represent these 9 ellipticals whose properties are discussed later in the text.

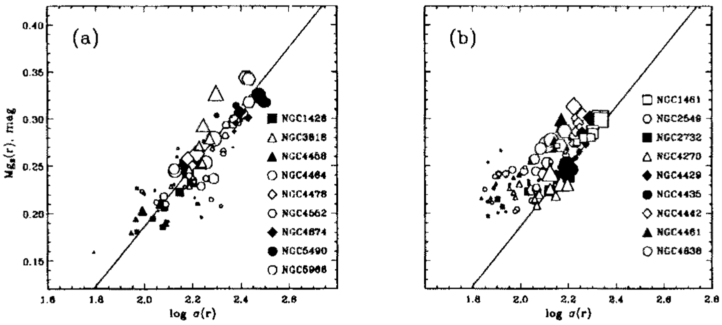

Fig. 2. The local $Mg_2(r) - \log \sigma(r)$ relationship for (a) 9 *bona-fide* elliptical galaxies, and (b) 9 S0 galaxies. Each galaxy is shown with different symbols and the larger the symbol, the closer is the measured radial point to the galaxy's center. The solid line represents the fit to the central relationship for 308 *bona-fide* ellipticals shown in Fig. 1.

3. 2. THE LOCAL $Mg_2(R) - \log \sigma(R)$ DIAGRAM

We have studied the Mg_2 vs. $\log \sigma$ for the local parameters, $Mg_2(r)$ and $\sigma(r)$, derived from the radial profiles of the Mg_2-index and σ over the major axes of both 9 *bona-fide* ellipticals and 9 S0s selected by us from our spectral archive.

Local $\mathrm{Mg}_2(r) - \log\sigma(r)$ relationships for selected ellipticals and lenticulars are presented in Fig. 2(a) and (b) respectively. Each galaxy is shown with different symbol and the larger the symbol, the closer is the measured radial point to the center of the galaxy. The solid line represents the fit to the central relationship for 271 *bona-fide* ellipticals shown in Fig. 1.

Only profile values for which the relative errors $\Delta\mathrm{Mg}_2(r)/\mathrm{Mg}_2(r) \lesssim 25\%$ and $\Delta\sigma(r)/\sigma(r) \lesssim 25\%$ were used for the analysis and plots.

The local relationship for ellipticals studied by us does not differ significantly from the central one for 308 objects. However, this is not the case of lenticulars. The two local relations, for E and S0 galaxies, are significantly different in sense that

1. The S0s have a slightly higher Mg_2 at given $\sigma(r)$ than the ellipticals. This effect is also apparent for the central values in Fisher et al. (1996 - see their Fig. 2), though not discussed there.
2. The local $\mathrm{Mg}_2(r) - \log\sigma(r)$ relationship for S0s *flattens* for low values of $\sigma(r)$ which does not occur for ellipticals. This also corresponds to the outer regions of these galaxies where the disk is predominant over the bulge.

4. DISCUSSION

This difference would mean that the disks of S0s are both old and have a high metallicity. Can this be reconciled with the dissipative collapse enrichment?

The standard model explains the $\mathrm{Mg}_2 - \log\sigma$ relation, either central or local, as a result of enrichment during the bulk of star formation. The fraction of metal-enriched gas left by the supernova-driven winds depends on the local escape velocity (see e.g. Franx & Illingworth 1990). In the framework of such a scenario, a disk having a different history would probably depart from the *bona-fide* $\mathrm{Mg}_2 - \log\sigma$ relation.

An alternative could be to consider the simultaneous dissipative formation of both the disk and the bulge. In such case, the enrichment will be controlled by the local potential, $\Phi(r)$. And if the system has only passively evolved after the bulk of star formation, the $\Phi(r) - \mathrm{Mg}_2(r)$ relation should keep traces of this star-formation process.

Potentials of elliptical and lenticular galaxies are basically different. In the case of S0s, the local velocity dispersion $\sigma(r)$ cannot be used as an estimate of the local potential $\Phi(r)$. The structure and dynamics of lenticulars is more complex, and, as a minimum, it is necessary to include the rotational velocity, V_{rot}, in the estimate of the local kinetic energy.

In the framework of axis-symmetric dynamical models, both oblate and prolate (see e.g. van der Marel 1991), for every point of the major axis the local kinetic energy *projected* over the LOS is $V_{\mathrm{rot}}^2(r) + \sigma^2(r)$. As it was shown by Prugniel & Simien (1994) for ellipticals, the rotational energy, being usually small but not negligible, should always add a positive contribution to the total kinetic energy.

This additional energy could be described by the dimensionless rotational-support term $S \simeq \frac{1}{2}\log(1+\eta V_{\mathrm{rot}}^2/\sigma^2)$. The term was introduced by Prugniel & Simien (1994) in frame of their analysis of contribution of the galactic rotation to the virial equilibrium in ellipticals, and they derived $\eta = 0.81$ for isotropic rotators. Hence, we have studied the relation between the residuals

$$R(r) = \log\,\sigma_{\mathrm{Mg}_2}(r) - \log\,\sigma(r) \tag{2}$$

to the local $\mathrm{Mg}_2(r) - \log\sigma(r)$ relation as a function of the *local projected* rotational support expressed as

$$S(r) = \frac{1}{2}\log\left(1 + \eta V_{\mathrm{rot}}^2(r)/\sigma^2(r)\right). \tag{3}$$

Here $\log\,\sigma(r)$ is the observed velocity dispersion at given radial point of galaxy's major axis, and $\log\,\sigma_{\mathrm{Mg}_2}(r)$ is the value of the velocity dispersion predicted by Eq. 1., rewritten for the velocity dispersion.

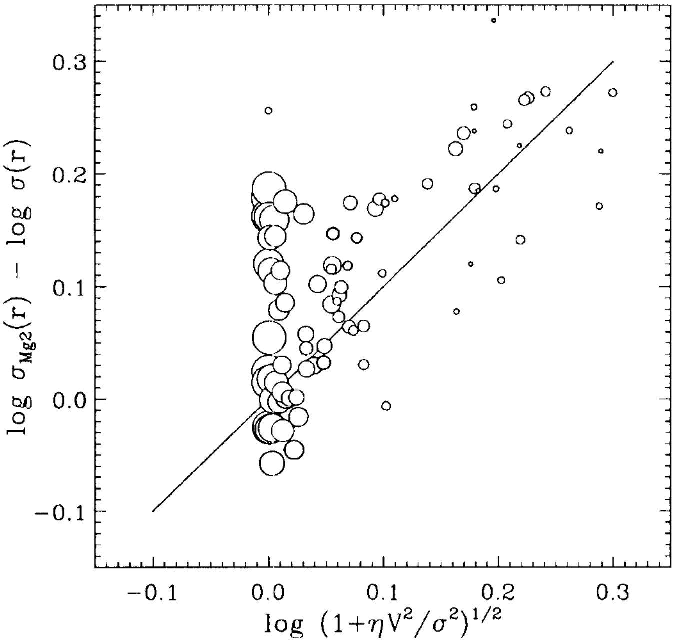

Fig. 3. The residuals $R(r) = \log\,\sigma_{\mathrm{Mg}_2}(r) - \log\,\sigma(r)$ for the profiles of all 9 lenticulars as a function of the local rotational support $S(r) = \frac{1}{2}\log(1 + \eta V_{\mathrm{rot}}^2(r)/\sigma^2(r))$. The 45° line (or the "best-fit" line in the sense of Eq. 4.) is shown. The larger the symbol, the closer is the radial point to the galaxy's center.

The analysis shows that the accounting for the rotational support leads the local $\mathrm{Mg}_2(r) - \log\sigma(r)$ relation for all S0s to become like that for the ellipticals. In Fig. 3. we present the diagram $R(r)$ vs. $S(r)$. The coefficient η has been determined for all lenticulars taken together by variation of $S(r)$ in order to achieve

$$\sum_r \left(R(r) - S(r)\right)^2 = \mathrm{Min}. \tag{4}$$

The result of this analysis is shown in Fig. 4. There the relation $\mathrm{Mg}_2(r)$ vs. $\frac{1}{2}\log(\sigma^2(r) + \eta V_{\mathrm{rot}}^2(r))$, which accounts for the local rotational support $S(r)$ to the total kinetic energy, is presented for the profiles of all 9 S0 galaxies studied by us. The mean value of $\eta \approx 1/2$ is derived.

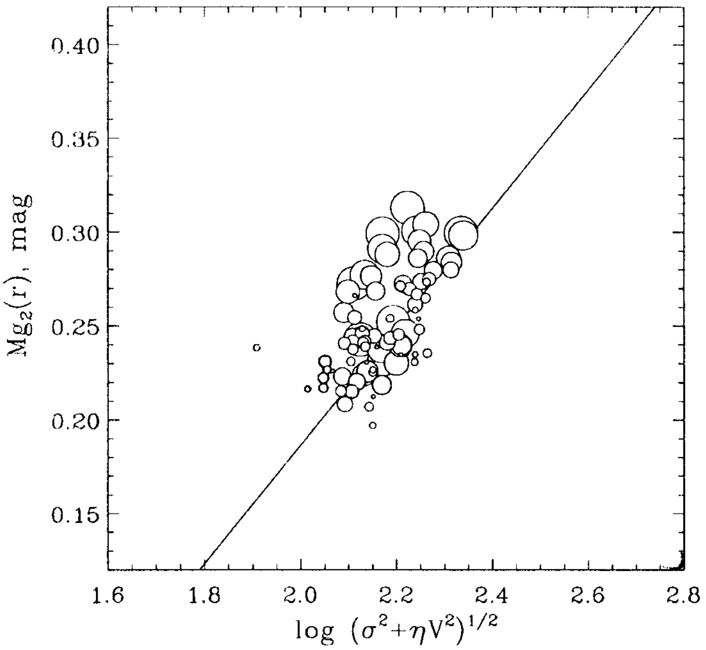

Fig. 4. The relation $\mathrm{Mg}_2(r)$ vs. $\frac{1}{2}\log(\sigma^2(r) + \eta V_{\mathrm{rot}}^2(r))$ for the profiles of all 9 S0 galaxies which accounts for the local rotational support $S(r)$ to the total kinetic energy. The mean value of $\eta \approx 1/2$ is derived. As before, the larger the symbol, the closer is the radial point to the galaxy's center.

5. CONCLUSION

We have investigated the local $\mathrm{Mg}_2(r)$ vs. $\log\sigma(r)$ relationship of 9 typical elliptical and 9 typical S0 galaxies. The two relations, for E and S0 galaxies, are significantly different.

The contribution of the rotation to the local potential, or rather, to the local potential *at the time* of star formation bulk, could provide an explanation of this difference. This would mean that the disks of S0s are both old and have a high metallicity. But the values of η derived by us are yet phenomenological only and need to be discussed in the framework of precise dynamical models.

Nevertheless, the qualitative difference between the local $\mathrm{Mg}_2(r) - \log\sigma(r)$ relationship of S0s and ellipticals may still be compatible with a model of dissipative quasi-simultaneous formation of the disk and the bulge.

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