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CHEMICAL ABUNDANCES AND GAS CONTENT IN DISK GALAXIES: CORRELATIONS WITH THE λ SPIN PARAMETER

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RESUMEN

Usando un modelo simple y general para describir la dinámica de las galaxias de disco, estimamos el parámetro de espín λ para una muestra de galaxias observadas y presentamos un estudio que muestra cómo varias propiedades físicas se encuentran relacionadas intrínsecamente con la dinámica de los sistemas. Aún cuando las correlaciones entre metalicidad promedio y magnitud o tipo de Hubble son evidentes, nosotros obtuvimos correlaciones igualmente fuertes con el espín, en el sentido de que galaxias con valores pequeños de λ presentan abundancias mas altas, mientras que galaxias con λ grande son pobres en metales. También el contenido de gas en las galaxias se correlaciona con λ, en donde sistemas con valores altos de λ presentan mayores fracciones de masa de gas que galaxias con valores pequeños de λ, destacando el importante papel que juega este parámetro en la estructura de las galaxias de disco y la propuesta de su uso como una medida del tipo morfológico.

ABSTRACT

By using a very simple and general model to describe the dynamics of disk galaxies, we estimate the λ spin parameter for a sample of observed galaxies and present a study in which we show that several important physical properties are intrinsically related to the dynamics of the systems. Although correlations between average metallicity with magnitude or Hubble type are evident, we obtain equally strong correlations with the spin parameter, where galaxies with low λ values present higher abundances and galaxies with high λ values are poor in metals. Also, the gas content of the galaxies correlates with λ, with high λ systems showing higher gas mass fractions than low λ galaxies, highlighting the important role this parameter plays in the structure of disk galaxies and the proposal of λ as a robust and objective physical measure of galactic morphology.

Key Words: galaxies: abundances — galaxies: fundamental parameters — galaxies: general — galaxies: structure

1. INTRODUCTION

One recurrent issue in the study of galaxies is their classification, most frequently treated through the Hubble type (Hubble 1926, 1936). This classification scheme is extensively used and owes it success to the ample and broad range of physical characteristics involved in its construction, such that all show good monotonic correlations with it. Just to mention some of them, total magnitudes decrease towards later types (e.g. Ellis et al. 2005), and colours become bluer going from early to late types (e.g. Roberts & Haynes 1994), the blue magnitudes and bulge to disk ratios decrease (e.g. Pahre et al. 2004) and disks become thinner (e.g. Kregel, van der Kruit, & de Grijs 2002) going to late types.

All these clear correlations point towards the notion that the sequence of morphologies indicates an underlying sequence of values for one or more physical parameters, which ultimately determine the type of the galaxies. The Hubble scheme of classification owes its success precisely to this fact; it orders galaxies by properties that reflect essential physics, but not without some shortcomings. The classifica-

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tion of galaxies using this scheme is usually done by visual inspection and requires skill and experience, which not only makes it a subjective scheme, but also renders it impractical when dealing with large samples containing hundreds or thousands of galaxies, as is the case of the Sloan Digital Sky Survey (SDSS) or the 2dF Galaxy Redshift Survey. Naim et al. (1995) and Lahav et al. (1995), studied the agreement between expert morphologists classifying different samples of galaxies and both collaborations reported a non-negligible scatter between observers, making the subjective character of the Hubble scheme evident.

Another important problem with the Hubble scheme is that it is based on a qualitative analysis of observable features, which makes it difficult to relate type to definitive quantitative physical aspects of a galactic system. That the scheme is ultimately qualitative casts serious doubts on the validity of any statistical analysis performed on galactic populations based on galactic type.

The study of high-z galaxies whose light has been redshifted into other bands, shows a wavelength dependence of morphology for different Hubble types. In general, it is found (Kuchinski et al. 2000) that the dominance of young stars in the far-ultraviolet produces the patchy appearance of a morphological type later than inferred from optical images. Apart from the observational band dependence, the low signal-to-noise levels in faint images of distant galaxies, projection effects and low resolution, can strongly affect the morphological type assigned to a given galaxy (e.g. Abraham et al. 1994). This makes the Hubble scheme relative to the observation band, the redshift and the orientation available for a given galaxy, as the spiral arms vanish for edge-on disks.

From the theoretical study of galactic structure and formation, it generally emerges that the principal physical origin of galactic type morphology, lies in the choice of mass and angular momentum. Some examples of the above are: Fall & Efstathiou (1980), Firmani, Hernández, & Gallagher (1996), Dalcanton, Spergel, & Summers (1997), Mo, Mao, & White (1998), and van den Bosch (1998). Theoretically, the observed spread in many physical features of the galaxies can be understood as arising from a spread in the halo angular momentum once the mass has been fixed, coupled with a spread in the formation redshifts, this last once a particular formation model has been assumed. For example, the bulge to disk ratio (van den Bosch 1998), the thickness of the disk (Kregel, van der Kruit, & Freeman 2005), the surface density (Dalcanton et al. 1997), systematic variations in the slope of rotation curves (Flores et al. 1993), scalelength (Hernández & Gilmore 1998; Jiménez et al. 1998), chemical abundances and color gradients (Prantzos & Boissier 2000), and gas content, abundance gradients (Churches, Nelson, & Edmunds 2001; Boissier et al. 2001) and the spread in the Tully-Fisher relation, once the slope is determined by the total galactic mass (Koda, Sofue, & Wada 2000), to mention but a few. Hence, the proposal of the angular momentum as the principal physical parameter responsible for the Hubble sequence (Silk & Wyse 1993; van den Bosch 1998; Zhang & Wyse 2000; Firmani & Ávila-Reese 2003) is not surprising. It has often been suggested that the angular momentum of a galaxy should be an adequate proxy for the Hubble sequence, or rather, that it is precisely this parameter the one for which the Hubble sequence has been serving as a proxy of.

In Hernández & Cervantes-Sodi (2006, henceforth Paper I), using a sample of observed galaxies, we presented a series of correlations confirming the dependence on angular momentum of several key structural parameters such as disk to bulge ratio, thickness of the disk and rotational velocity, and in Hernández et al. (2007, Paper II), we matched Hubble type with the angular momentum parameter using a color versus color gradient criterion (Park & Choi 2005), where the segregation by angular momentum coincides with the segregation by Hubble type, as visually assigned for a large sample of spiral galaxies from the SDSS.

In the present work, we give a general review to introduce the use of the angular momentum parameter as a physical classification criterion for spiral galaxies, which we reinforce by presenting additional independent correlations recently found. In § 2 we present the underlying ideas behind proposing physical correlations between structural galactic parameters and angular momentum, and an account of previous results, in § 3 we explore possible scalings between chemical abundances, gas content and angular momentum, which we test in § 4. § 5 presents a discussion of our results and general conclusions.

2. THEORETICAL FRAMEWORK

A generally accepted picture for galaxy formation is the ΛCDM model, where overdense regions of the expanding Universe at high redshift accrete baryonic material through their gravitational potential to become galaxies. Their principal global characteristics, according to theoretical studies, are determined by their mass and angular momentum. The angular momentum is commonly characterized by the dimensionless angular momentum parameter (Peebles

1969)

$$\lambda = \frac{L \mid E \mid^{1/2}}{G M^{5/2}}\,, \tag{1}$$

where E, M and L are the total energy, mass and angular momentum of the configuration, respectively. In Paper I we derived a simple estimate of λ for disk galaxies in terms of observational parameters, and showed some clear correlations between this parameter and structural parameters, such as the disk to bulge ratio, the scaleheight and the colour. Here we briefly recall the main ingredients of the simple model. The model considers only two components, a disk for the baryonic component with an exponential surface mass density $\Sigma(r)$:

$$\Sigma(r) = \Sigma_0 e^{-r/R_d}\,, \tag{2}$$

where r is a radial coordinate and Σ_0 and R_d are two constants which are allowed to vary from galaxy to galaxy, and a dark matter halo having a singular isothermal density profile $\rho(r)$, responsible for establishing a rigorously flat rotation curve V_d throughout the entire galaxy:

$$\rho(r) = \frac{1}{4\pi G}\left(\frac{V_d}{r}\right)^2. \tag{3}$$

In this model we are further assuming: (1) that the specific angular momentum of the disk and halo are equal e.g. Fall & Efstathiou (1980), Mo et al. (1998), Zavala, Okamoto, & Frenk (2008); (2) that the total energy is dominated by that of the halo which is a virialized gravitational structure; (3) that the disk mass is a constant fraction of the halo mass; $F = M_d/M_H$ (Brooks et al. 2007; Crain et al. 2007). These assumptions allow us to express λ as

$$\lambda = \frac{2^{1/2} V_d^2 R_d}{G M_H}\,. \tag{4}$$

Finally, we introduce a baryonic Tully-Fisher relation: $M_d = A_{TF} V_d^{3.5}$, in consistency with Gurovich et al. (2004) and Kregel et al. (2005). We see the total mass fixing the bulk dynamical structure of the galaxy, with internal distributions being then determined by the choice of λ, e.g. Fall & Efstathiou (1980) and references thereof. Taking the Milky Way as a representative example, we evaluate F and A_{TF} to obtain

$$\lambda = 21.8 \frac{R_d/\mathrm{kpc}}{(V_d/\mathrm{km\ s^{-1}})^{3/2}}\,. \tag{5}$$

The accuracy in our estimation of λ is proved in Cervantes-Sodi et al. (2008), comparing the estimation using equation (5) with the values arising from numerical simulations of six distinct groups, where the actual value of λ is known, as it is one of the parameters of the simulated galaxies, and where we can also estimate it through equation (5), as baryonic disk scale lengths and disk rotation velocities are part of the output. This shows a one-to-one correlation, with very small dispersion leading to typical errors $< 30\%$. This level of accuracy is encouraging, when comparing what is little more than an order of magnitude estimate against detailed physical modeling spanning a wide range of masses and λ values, including disk self-gravity, the presence of galactic bulges, detailed dark halo structure and often complex formation histories. The only ambiguity which remains in assigning a value of λ to an observed galaxy through equation (5), is in the choice of the restframe band in which the disk scalelength is to be measured. This is clearly to be chosen in a way which maximally reflects the underlying mass distribution, and not the recent star formation, highly sensitive to a small number of young stars. Therefore, the restframe band in which R_d is to be measured if equation (5) is to be used optimally, is a red or infrared one, see Paper I.

Having an estimate for the spin parameter, we applied it to a large sample of disk galaxies taken from the SDSS. Park & Choi (2005), showed a criterion using the colour versus colour gradient plane, to separate galaxies by galactic type, from early to late type (see Figure 1, left panel). We see the ellipticals appearing in a very compact region, with red colours and minimal colour gradients. In Figure 1 right panel, are plotted the 7,753 galaxies from the SDSS sample of Paper II, in the same color versus colour gradient plane, where the shading gives the average values of λ within each shaded square, calculated through equation (5). We can see that high λ disk galaxies are located in the lower left area of the plane, occupied by later types in Figure 1 left panel, whilst low λ disk galaxies populate the right upper zone, precisely where earlier types are evident in Figure 1 left panel. Comparing with the spread of galactic types, the match of late spirals with high λ values and early spirals with low λ values is validated.

With equation (5) in Paper I we showed several correlations between λ and physical features of disk galaxies such as: the disk to bulge ratio, one of the main morphological parameters that sets the classification of galaxies in the revised Hubble diagram (van den Bosch 1998), which decreases when λ increases, while the thickness of the disk diminishes and the colour becomes bluer. A clear trend for mean λ val-

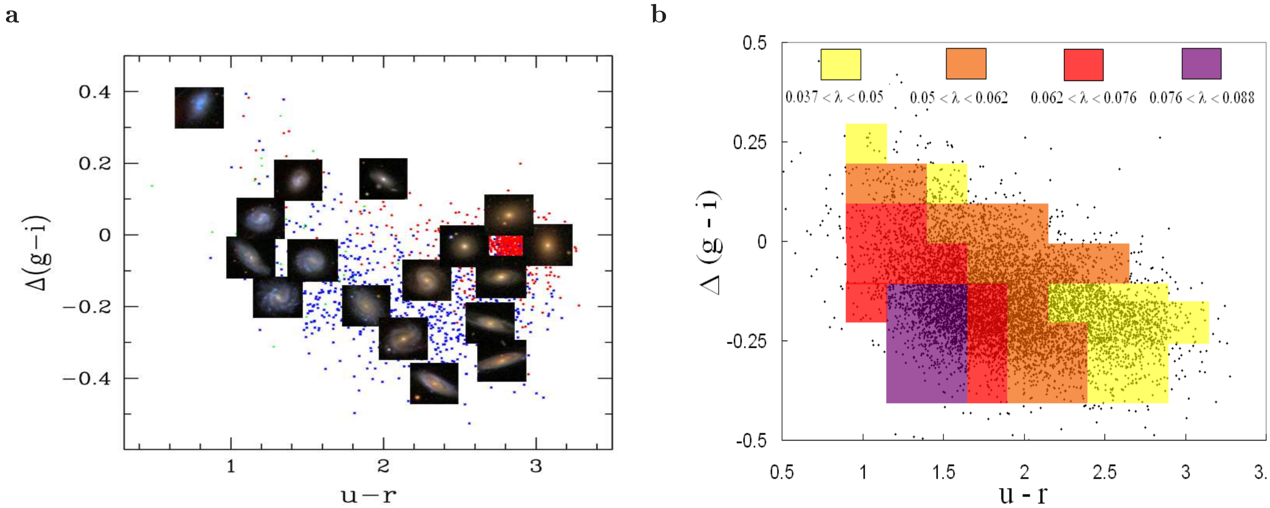

Fig. 1. (a) Sample of galaxies from Park & Choi (2005) in a color, color-gradient plane, with photos of galaxies representative of the morphological type found in each region. (b) Spiral galaxies from Paper II on a color, color-gradient plane; the shading shows the average λ value in each shaded region, calculated using equation (5).

ues increasing in going towards later Hubble types, as visually assigned, was also established. In the following section we present the underlying ideas behind expecting additional correlations involving gas fractions and chemical abundances, with the aim of reinforcing the use of λ as an objective and quantitative classification tool.

3. EXPECTED CORRELATIONS BETWEEN λ AND CHEMICAL ABUNDANCES AND GAS CONTENT

The gas mass and chemical composition in disk galaxies span wide ranges, early-type galaxies presenting systematically lower gas mass fractions and higher metallicity abundances (Vila-Costas & Edmunds 1992; Oey & Kennicutt 1993; Roberts & Haynes 1994; Zaritsky, Kennicutt, & Huchra 1994, hereafter ZKH). As pointed out by Kennicutt et al. (1993), it is tempting to associate the higher abundances with the early morphological types, but differences in other parameters such as galaxy luminosity or rotational velocity may also be important. Over the last twenty years there have been several studies exploring the connection between metallicity and other physical parameters of galaxies; luminosity, rotational velocity and mass, among others.

The correlation between metallicity and luminosity, in the sense that the higher the luminosity of the system, the higher the metal abundance, is now well established e.g. Garnett & Shields (1987), Hunter & Hoffman (1999), Pilyugin (2001), and Melbourne & Salzer (2002). Thinking of the luminosity as a tracer for the mass of the galaxy, and given the Tully-Fisher relation, we find equally a metallicity rotation velocity relation. Compared with the luminosity metallicity relation, the above shows no qualitative difference (Garnett 1998), only a slightly better correlation, presumably due to differences among mass to light ratios. The mechanism that might be responsible for the origin of such correlations is, at present, open to debate, but the most common hypothesis is the loss of heavy elements through galactic winds (e.g. Franx & Illingworth 1990; Kauffmann 1996; Pilyugin, Vílchez, & Contini 2004, hereafter PVC) in low mass galaxies, while higher mass galaxies present deeper gravitational potentials and lower heavy elements losses. The correlation with Hubble type, however, is more difficult to explain given the fact that this last is not a physical parameter as such.

If besides the mass, there is another physical parameter which determines abundances in galaxies, it should correlate with the Hubble type. It is reasonable to think that the angular momentum parameter could play an important role. In order to see how a causal relation between λ and both the characteristic abundances and gas content of galaxies might arise, one can start from the star formation rate (SFR), assuming a generic Schmidt law in terms of SFR surface density and gas surface density:

$$\Sigma_{SFR} \propto \Sigma^{n} \,. \tag{6}$$

We define the star formation efficiency ϵ evaluated at R_d as:

$$\epsilon = \frac{\Sigma_{SFR}(R_d)}{\Sigma(R_d)} \propto \Sigma_0^{n-1} \,, \tag{7}$$

and using equation (2), we can write Σ_0 in terms of the mass of the disk and the scalelength, from where the dependence in R_d can be replaced by a dependence in λ at fixed mass, resulting in

$$\epsilon \propto \lambda^{2(1-n)} . \qquad (8)$$

Both empirically (Kennicutt 1998; Wong & Blitz 2002) and theoretically (Tutukov 2006) inferred values for n fall in the range 1–2, being 1.4 a standard value; in this case, we have $\epsilon \propto \lambda^{-0.8}$, in agreement with previous results from theoretical studies (Boissier et al. 2001). For any value of n in the cited range (excluding one of the extremes), the exponent in equation (8) is negative, so systems with large λ values will show typically low star formation efficiencies, while galaxies with small λ may present a very efficient star formation process. In other words, extended galaxies, with large scalelengths for their total mass, present lower star formation efficiencies than more compact ones, those with small scalelength at a given mass. The scaling corresponding to equation (8), for ϵ as a function of mass at fixed λ yields $\epsilon \propto M^{(n-1)/7}$. For standard values of n, we see the expected positive correlation of ϵ vs. mass, opposite to what happens vs. λ, leading to an increasingly later type appearance as one goes to larger masses, at fixed λ.

Studying the chemical and spectrophotometric evolution of galactic disks, using semi-analytic models of galactic evolution, Boissier & Prantzos (2000) reached similar conclusions. In their models, the shortest characteristic time-scales correspond to the more massive and compact disks with smaller λ values, favoring rapid early star formation and the existence of relatively old stellar populations today.

From equation (8), the most efficient galaxies at forming stars and therefore metals, are the compact ones, with low λ values, being also the most efficient at turning their gas into stars. If we assume that all galaxies start forming stars at the same time and that the amount of gas in each of them is proportional to their gravitational potential, extended galaxies with high λ should appear today to be systems with large amounts of gas and poor in metals, while compact galaxies, with low λ and very efficient at forming stars at the onset, will now be systems poor in gas with large metal abundances. Prantzos & Boissier (2000) reported this same result arising from their semi-analytic models, where the most compact disks with low λ values presented the higher abundances, being this type of galaxies the most efficient at forming stars and metals, consuming their gas and showing low gas mass fractions. The above applies only to large and medium disk galaxies; the clear mass metallicity relation in spheroidal systems, from dSphs to elliptical galaxies, systems where the angular momentum plays only a very minor role, most probably arises from the differential efficiencies of galactic winds. We see how the two parameter nature of galactic systems reduces to a one parameter space when one goes from the spirals to the ellipticals, where the angular momentum becomes close to negligible and ceases to determine the internal structure of the galaxy to any substantial level.

4. OBSERVATIONAL DATA COMPARISONS

The observational data used to check our expected correlations were compiled by PVC. The compilation comprises more than 1000 published spectra of HII regions in 54 spiral galaxies. The oxygen and nitrogen abundances were obtained using the P-method described in Pilyugin (2003).

For the present work, we used the exponential scalelengths measured by Garnett (2002), ZKH, and Elmegreen & Elmegreen (1984), for 36 of the 54 galaxies in the PVC sample, preferentially using reported values in red bands in order to account for the mass distribution of the galaxy. Using the rotation velocity reported in PVC we calculate λ for each galaxy in the sample using equation (5). As described in the previous section, we expect galaxies with low λ values to present very efficient early star formation processes, capable of enriching their interstellar media with metals, and hence presenting today higher oxygen abundances than the more extended galaxies with higher λ, where we would expect lower oxygen abundances. To check this, we employed the characteristic oxygen of the galaxies, defined as the oxygen abundance in the disk at $r = 0.4R_{25}$, following ZKH. In Figure 2 we show the characteristic oxygen of the sample as a function of λ (top panel) and type (bottom panel), the straight line being the best linear fit to the data, described by the equation:

$$12 + \log(O/H) = -3.401(\pm 0.037)\lambda + 8.667(\pm 1.03), \qquad (9)$$

which gives also the $1-\sigma$ uncertainties in the parameters of the fit, given our 30% uncertainties in the estimates of individual λs. The figure shows a clear correlation between the characteristic oxygen and λ, with a correlation coefficient of -0.493. Despite the large error bars and high dispersion, large empty regions to the upper right and lower left are evident. The above correlation coefficient is comparable to that obtained against rotation velocity of

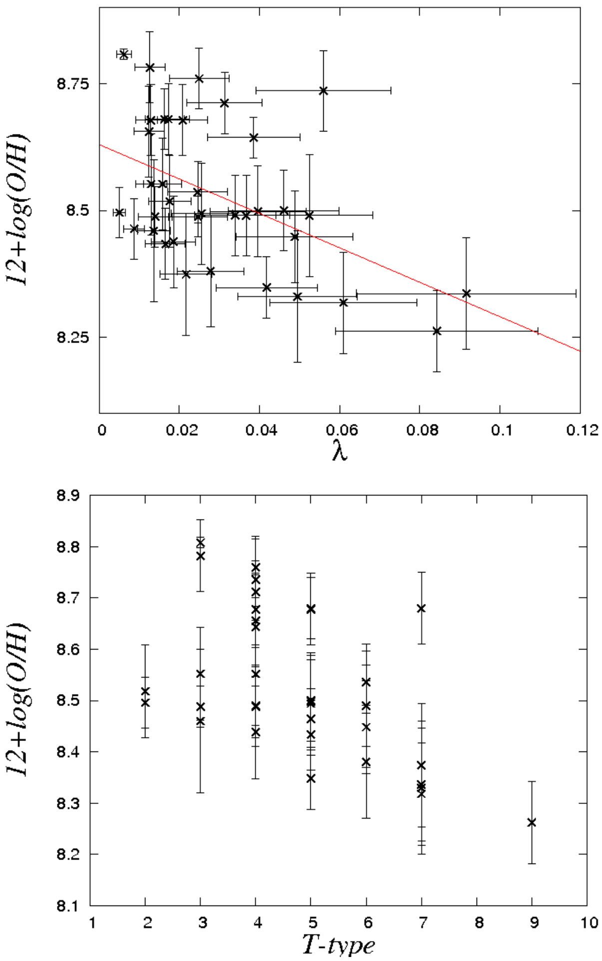

Fig. 2. Characteristic oxygen abundance as a function of λ (top panel) and type (bottom panel) for the 36 galaxies in the PVC sample for which disk scale lengths in red bands are available. The solid line is the best linear fit to the data.

0.608, or against luminosity of 0.469, for the correlations against characteristic oxygen. The average value of the dispersion in characteristic oxygen for the sample used in Figure 2 is of 0.136 dex. Although the spread seen in this figure could be intrinsic, it is also consistent with the internal errors in the estimates of λ; in this sense, the metallicity λ relation could in fact be much tighter than what the figure shows. The good correlation against rotation velocity mentioned above, given the Tully-Fisher relation, highlights again the equally important role of mass in galactic structure and evolution, as often recognised.

The trend with λ is clearer than the trend with type, the upper panel of Figure 2 gives a metallicity vs. λ relation, having the advantage of the entirely objective nature of its calculation and of it being quantitative, hence useful for meaningful statistics or to establish mathematical relations with other physical parameters such as equation (9). It must be taken into account that the assigned type of each galaxy is entirely subjective and not free of errors due to lack of information; in this sense we could assign error bars to the data plotted in Figure 2, spanning up to three types around the reported value.

From Figure 2, it is clear that the correlation of the metallicity of the galaxies with λ is as strong as that of metallicity against both the rotational velocity and the luminosity or, given the Tully-Fisher relation, the mass of the system. From the data we see that the studied properties of the galaxies are largely determined by fixing the mass and λ, but until now, we are not sure if the dependence with λ is only a reflection of the mass metallicity relation. In order to separate the respective dependencies, we can plot the residuals of the relation of the metallicity with one of the variables and test if they correlate with the other variable. To trace the mass of the galaxies we chose the absolute magnitude, because to calculate λ using equation (5) we employed V_d; in this form the measurement will be completely independent. In Figure 3 are plotted the residuals: (a) to the $O/H - \lambda$ relationship, plotted against M_B and (b) to the $O/H - M_B$ relationship, plotted against λ. We can see a correlation in both cases which indicates a systematic variation due to both variables, the mass and λ, as we expected. We hence see that the metallicity is a function of both mass and λ. As often found in theoretical studies of galactic formation and evolution, we see observable properties of galaxies appearing as two parameter families of solutions, determined by the choice of mass and λ.

A similar test was done by ZKH using the Hubble type and the velocity as a measure of the mass, and they found no clear trends, perhaps because the Hubble type is not an objective, quantitative physical parameter, while λ satisfies these conditions.

Results from several surveys of galactic abundances show clearly that most disk galaxies present negative abundance gradients similar to what is observed in our own galaxy (Henry & Worthey 1999). While characteristic abundances increase with galactic mass, no correlation has been found between metallicity gradients, normalized to the respective galaxy's isophotal radius, and mass. If instead of using the gradient normalized to the isophotal radius, the gradient is measured in dex kpc^{-1}, a correlation appears, such that more luminous galaxies have flatter slopes (Garnett 1998). With this in mind, we

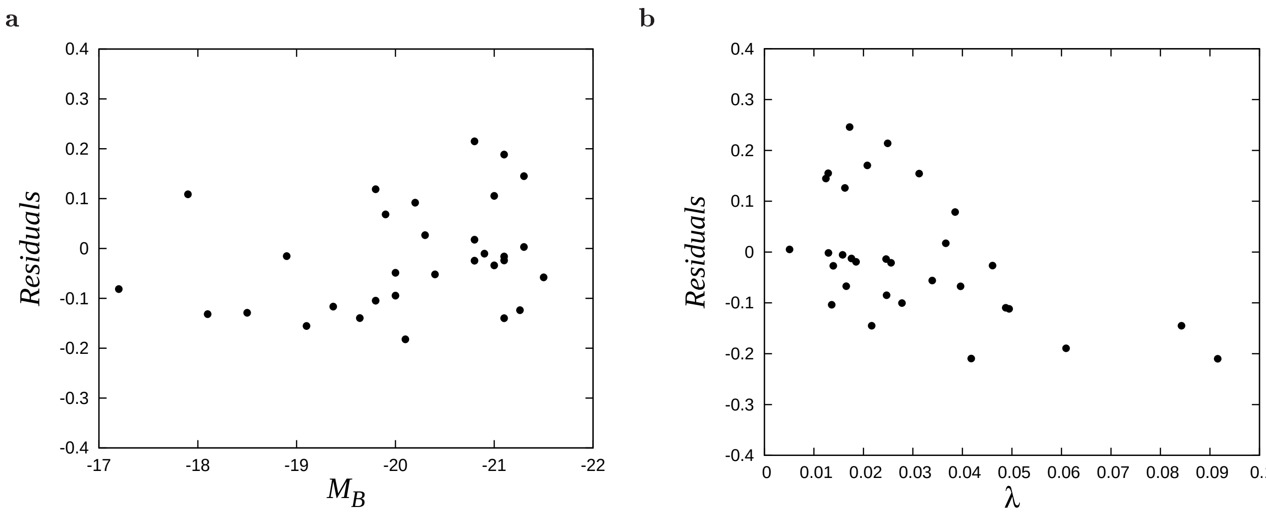

Fig. 3. The residuals to correlations. (a) Residuals to the $O/H - \lambda$ relationship, plotted against M_B. (b) Residuals to the $O/H - M_B$ relationship, plotted against λ.

search for a dependence of the abundance gradients with λ. The abundance gradients of the galaxies in the PVC sample are given in dex/R_{25} and we find no clear trend with λ, as predicted in theoretical studies (see below), but trends between λ and abundance gradients in dex kpc^{-1} have been predicted. Theoretical studies by Churches et al. (2001) show that both the gaseous and stellar abundance gradients in dex kpc^{-1} are functions of λ in the sense that increasing λ generally produces shallower gradients, and Prantzos & Boissier (2000) predicted that this effect should be more marked in low-mass disks.

To study this relation we employed a sample of 38 galaxies from ZKH, where the oxygen abundance gradients are given in dex kpc^{-1}. Using the reported disk scale length and the rotation velocity for each galaxy we obtain λ, again using equation (5). A plot of the abundance gradient as a function of λ is presented in Figure 4, where the sample has being split into 3 slices, through a luminosity ranking, each one containing one third of the total sample. The top panel presents the galaxies with the higher luminosities showing almost a constant value and very low dispersion, the middle panel again shows low dispersion and in general low gradients, but as we move to the smaller galaxies (bottom panel), the dispersion increases, showing deeper gradients for galaxies with low λ, confirming the theoretical predictions of Churches et al. (2001) and Prantzos & Boissier (2000), where in low-mass galaxies the increase of λ produces shallower gradients. Again, the two parameter nature of galaxies becomes apparent in the two fold dependence of abundance gradients against both mass and λ, the role played by the mass being predominant in this case.

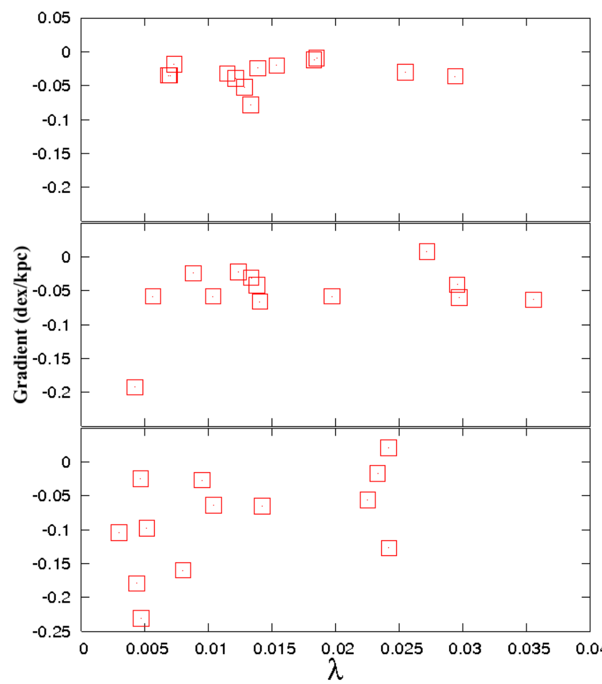

Fig. 4. Abundance gradients for the 38 galaxies from the ZKH sample, as a function of λ. From top to bottom, subsets of the sample splited by decreasing luminosity.

An extreme case would be that of the Low Surface Brightness galaxies, having very extended disks and large λ values (Hernández & Gilmore 1998) which then should exhibit small abundance gradients or none at all (Jiménez et al. 1998). Observations of de Blok & van der Hulst (1998), shows exactly this behavior, explained as a result of a constant evolution rate over the entire disk.

The high star formation efficiency of low spin galaxies should be reflected in the gas content of such systems. To measure this effect, we employed the gas fraction μ defined as:

$$\mu = \frac{M_{HI} + M_{H_2}}{M_{HI} + M_{H_2} + kL_B}, \tag{10}$$

where M_{HI} is the mass in atomic hydrogen, M_{H2} is the mass in molecular hydrogen, L_B is the blue luminosity, and k is the mass to luminosity ratio, here fixed to a value of $k = 1.5$, following the work of Garnett (2002). The value of μ reported in PVC, is plotted as a function of λ, estimated through equation (5), and type, in a logarithmic scale, and presented in Figure 5, where the solid line is a fit to the data corresponding to a relation between μ and λ of the form:

$$\log(\mu) = 0.384(\pm 0.159)\log(\lambda) + 0.082(\pm 0.097), \tag{11}$$

with a correlation coefficient of 0.562. Again, equation (11) gives also the $1-\sigma$ confidence intervals on the fitted parameters, given our uncertainties in λ. The average value of the dispersion shown by the data in Figure 5 is 0.167 dex. The clear trend in the expected sense given our hypothesis is as clear as that obtained with the rotational velocity, which presents a correlation coefficient of -0.605, slightly better than what is observed against the luminosity, with a correlation coefficient of -0.477. In comparison with type, the trend is similar, but in this case the allocation of λ is completely objective and quantitative, which allow us to calculate empirical correlations as equation (11), that would be senseless to try using type, given its qualitative nature.

Thinking of λ as the main physical determinant of galactic type, the large gas fractions and low metallicities found for both late type spirals and high λ systems in the sample we treat are consistent with the expectations of § 3. High λ disks have long star formation timescales, and hence appear today as low metallicity, high gas fraction systems. Hence, one would also expect these galaxies to show high present star formation rates, as low λ systems would have exhausted their gas fuel in the remote past. We note that Berta et al. (2008) recently adopted a slightly modified and higher accuracy version of equation (5) to determine λ for a large sample (52,000) of SDSS galaxies, and strongly confirm the relation between this physical parameter and galactic type. In the particular case of the recent star formation, which they accurately trace through detailed spectral synthesis modeling, they find a positive correlation with λ, which is what would be expected from the preceding argument. The work of Berta et al. (2008) offers independent support for both the high gas mass fractions and the low metallicities of high λ galaxies we found, after the critical dependence on total mass has been considered. Further, in that work the authors strongly support the identification of λ and mass as the parameters determining the Hubble sequence.

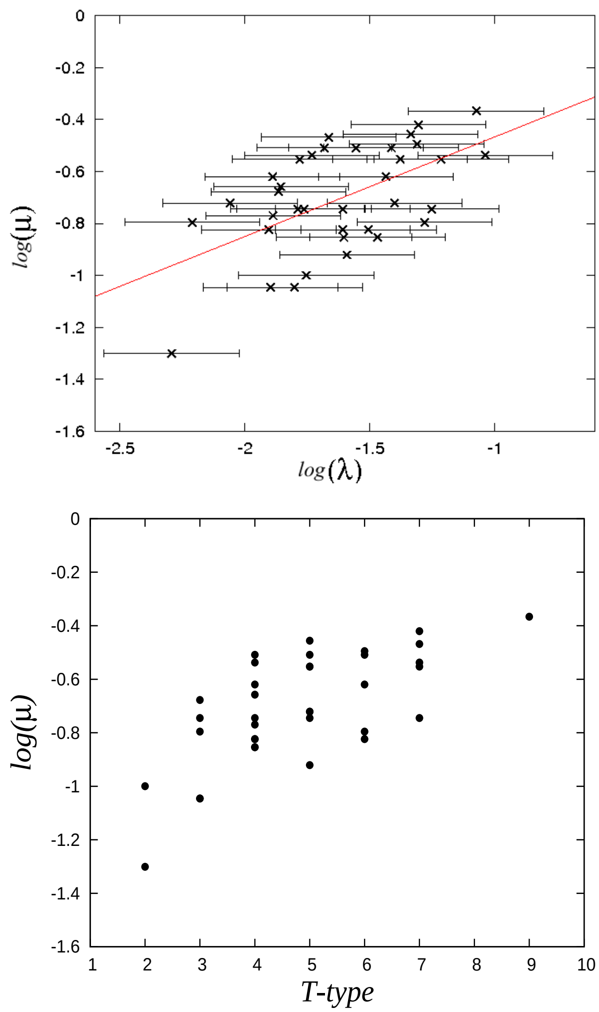

Fig. 5. Logarithmic plot of the gas fraction of the 36 galaxies from the PVC sample, as a function of λ (top panel) and type (bottom panel). The solid line is the best fit to the data.

5. CONCLUSIONS

We use a simple dynamical model for spiral galaxies to infer the value of λ for a sample of observed disk galaxies, for which detailed chemical and gas mass studies exist.

We confirm general results from theoretical studies of chemical galactic evolution: systems with low λ spin parameter present typically higher metallicities and lower gas mass fractions than systems with large λ. In low mass disk galaxies, the abundance gradients in dex kpc^{-1} are more pronounced for low λ systems. Asides from the trends found, we present numerical relations between the variables involved which could be used to calibrate numerical studies of galactic formation.

The trends here discussed together with correlations between λ and other physical observable parameters such as the disk thickness, the bulge to disk ratio, colour and colour gradients, as stressed by several authors (van der Kruit 1987; Dalcanton et al. 1997; van den Bosch 1998; Hernández & Cervantes-Sodi 2006; Hernández et al. 2007), reinforce the idea of the use of this physical parameter as an objective and quantitative tool for galaxy classification.

It appears clear that once the total mass of a galaxy has been fixed, and the integral properties hence determined (e.g. through the Tully-Fisher relation), it is λ what then establishes the internal structure, disk scale lengths, star formation efficiencies and other derived quantities.

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