Correlation between kinematics and Hubble Sequence in disk galaxies?

J.C. Vega Beltrán (jvega@pd.astro.it)
and E. Pignatelli (pignatelli@pd.astro.it)
Osservatorio Astronomico di Padova, vicolo dell’Osservatorio 5, I 35122 Padova, Italy

W.W. Zeilinger (wzeil@magellan.astro.univie.ac.at)
Institut für Astronomie, Universität Wien, Wien, Austria

A. Pizzella (apizzell@eso.org)
European Southern Observatory, Lasilla 19001, Santiago 19, Chile

E.M. Corsini (corsini@pd.astro.it)
and F. Bertola (bertola@pd.astro.it)
Dipartimento di Astronomia, Università di Padova, vicolo dell’Osservatorio 5, I-35122 Padova, Italy

J. Beckman (jeb@ll.iac)
Instituto de Astrofísica de Canarias, La Laguna, Spain

Abstract.
We present a comparison between ionized gas and stellar kinematics for a sample of 5 early-to-intermediate disc galaxies. We measured the major axis $V$ and $\sigma$ radial profiles for both gas and stars, and the $h_3$ and $h_4$ radial profiles of the stars. We also derived from the $R$-band surface photometry of each galaxy the light contribution of their bulges and discs.

In order to investigate the differences between the velocity fields of the sample galaxies we adopted the self-consistent dynamical model by Pignatelli & Galletta (1999), which takes into account the asymmetric drift effects, the projection effects along the line-of-sight and the non-Gaussian shape of the line profiles due to the presence of different components with distinct dynamical behavior. We find for the stellar component a sizeable asymmetric drift effect in the inner regions of all the sample galaxies, as it results by comparing their stellar rotation curves with the circular velocity predicted by the models.

The galaxy sample is not wide enough to draw general conclusions. However, we have found a possible correlation between the presence of slowly-rising gas rotation curves and the ratio of the bulge/disc half luminosity radii, while there is no obvious correlation with the key parameter represented by the morphological classification, namely the bulge/disc luminosity ratio. Systems with a diffuse dynamically hot component (bulge or lens) with a scale length comparable to that of the disc are characterized by slowly-rising gas rotation curves. On the other hand, in systems with a small bulge the gas follows almost circular motions, regardless of the luminosity of the bulge itself. We noticed a similar behavior also in the gas and stellar kinematics of the two early-type spiral galaxies modeled by Corsini et al. (1998).
1. Introduction

Evidence has been presented (Bertola et al. 1995) that in several S0 galaxies the gas in the inner regions shows broad velocity dispersion profiles. In addition, in the centers of certain early-type galaxies it was discovered (Fillmore et al. 1986; Kent et al. 1988) that the gas rotation curves fall down the circular velocities predicted by constant M/L models. Both gas phenomena: the “slowly-rising” rotation curve and the high velocity dispersion, can be well interpreted as signs of gas recently expelled by the stars of the bulge but not yet heated to the virial temperature of the galaxy (i.e. pressure-supported). In the case of the late-type spirals the picture is clearer: both the gas and the stars show essentially circular motions and constant velocity dispersion profiles.

It has been shown for Sa galaxies (Corsini et al. 1998) that the application of dynamical models can tell us a great deal about the structure and the kinematics of galaxies: understanding of the dynamics for the different stellar components, deviation of the gas from circular motions and the presence of dark matter. Here we present a comparison between the gas and stellar kinematics for a sample of 5 disc galaxies (see Table I) of early and intermediate Hubble types (Sa, Sb).

Table I. Parameters of the Sample Galaxies. Col.(3): total observed blue magnitude from RC3 except for NGC 5064 (RSA). Col.(4): inclination from NGB (Tully 1988) except for NGC 980 and NGC 7782 from RC3 (inferred from R25). Col.(5): systemic velocity derived from the center of symmetry of the gas rotation curve and corrected for local motion. Col.(6): distance obtained from V0/H0 with H0 = 75 km s^{-1} Mpc^{-1}. Col.(8): radius of the 25 B−mag arcsec^{-2} isophote from RC3.

| object [name] | type B_T | i | V0 [km s^{-1}] | D [Mpc] | scale pc/'' | R25 ['] |
|--------------|----------|---|---------------|--------|-------------|--------|
| NGC 772 .SAS3.. | 11.09 | 53 | 2618 | 34.7 | 168 | 217 |
| NGC 980 .L..... | ... | 62 | 5936 | 79.1 | 384 | 51 |
| NGC 3898 .SAS2.. | 11.60 | 46 | 1283 | 17.1 | 83 | 131 |
| NGC 5064 PSA.2* | 12.69 | 65 | 2750 | 36.7 | 178 | 74 |
| NGC 7782 .SAS3.. | 13.08 | 62 | 5611 | 74.8 | 363 | 72 |

The study of the Sb galaxies allows us to see whether non circular motions are present in the inner regions for both gas and stars, or if we are facing systems with intermediate kinematic properties between early and late-type objects as might be inferred from the photometric properties.
2. Observations and data deduction

Spectroscopic observations were carried out at ESO, La Silla (Chile) (ESO N. 60.A-0800), at the MMT operated on Tucson (Arizona) and at the INT operated on the island La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias (IAC), Tenerife (Spain).

Photometric observation were carried out at the IAC80 operated on the island Tenerife by the IAC in the Spanish Observatorio of Izaña, at the VATT operated on Tucson, and at ESO, La Silla (Chile) (ESO N. 60.A-0800).

The standard spectral reduction was performed by using the ESO-MIDAS package. The stellar kinematics was measured from the absorption lines present on each spectrum using the Fourier Correlation Quotient Method (Bender 1990) as applied by Bender, Saglia & Gerhard (1994). The ionized gas velocities and velocity dispersions were derived by means of MIDAS package ALICE. The photometric data reduction was carried out using standard IRAF routines.

3. The model

In order to investigate the different behavior of the gas and the stellar kinematics a self-consistent dynamical model (Pignatelli & Galletta, 1999; see also Pignatelli & Galletta, elsewhere in this volume) is used to reproduce the data.

The model has $4n + 1$ free parameters, where $n$ is the number of adopted components: namely the luminosity, scale length, mass-luminosity ratio and flattening $\{L_{Tot}, r_e, M/L, b/a\}$ of each component plus the inclination angle of the galaxy. In principle, all of these parameters can be constrained - within some confidence limits - by the photometry, with the exception of the M/L ratios, which have to be derived from the kinematics.

In order to compare the observed data with the predictions of the model, we also need to reproduce the deviations of the LOSVD from a pure Gaussian shape. We adopted the usual parameterization in terms of a Gauss-Hermite expansion series (van der Marel and Franx 1993; Gerhard 1993).

Once the fit of the stellar kinematics has been performed, and the overall potential of the galaxy is known, one can directly derive the circular velocity $V_c$. By superimposing the $V_c$ inferred in this way (and corrected for inclination) on the observed gas rotational velocity, we can immediately notice any deviation from purely circular motions.
4. Results

For shortness reason, we give in detail the results for only 2 of the 5 galaxies studied, and briefly summarize the other ones. We refer to the complete paper (Vega et al. 1999) for details.

**NGC 980:** The photometric model adopted for this lenticular galaxy is that of an almost edge-on disc component embedded in a lens much more extended than the disc itself, together with a very compact, luminous bulge in the inner 2′′ (see Fig. 1). The superposition of these 3 components accounts for the peak in ellipticity at 10″, and the subsequent slow decrease from $\varepsilon = 0.6$ to $\varepsilon = 0.3$.

The most interesting feature of this galaxy is surely the gas-stars kinematic difference. From 3″ to 10″ gas and stars appear to have quite a different behavior, with the gas raising linearly in velocity, while the stars do present a plateau. As a consequence, the gas is rotating faster at 3″ than the stars, and slower than the stars at 10″. On the other hand, both the components are following the same velocity dispersion curve, marking the likely association of the gas with a hot component. This difference between the gas and stellar rotational velocity is unlikely to be due only to absorption effect, and could be due to a misalignment between the gas and the stellar component, suggested also by the slow change of about 10° in the position angle of the $R$-band isophotes.

At 2″ it is also visible a small peak in the velocity, which is not evident in the gas rotation curve, and that we interpreted as the effect of the rotation of a massive central flattened distribution of matter, also responsible for the sharp increase in the velocity dispersion in the inner region. Finally, the presence of a lens is inferred from the slow decrease of the velocity dispersion, much slower than would be expected from a small bulge; as well as from the stellar LOSVD, strongly non-Gaussian at $r=8″$.

**NGC 7782:** This Sb galaxy looks like the prototype of a bulge+disc system, with the two components almost decoupled from each other. From both the kinematic and the photometric data we can distinguish two different regions with very different behaviors. In the inner 5″ region, dominated by an almost spherical bulge, the stellar velocity dispersion shows a plateau at $\sim 200$ km s$^{-1}$ and the rotational velocity is less than half the value expected from the circular velocity, in agreement with the asymmetric drift effect calculated by the model (see Fig. 2). On the other hand the gas shows strictly circular motions with low velocity dispersion. In the outer region, well approximated by an exponential disc, both the gas and the stars appear to rotate close to the circular velocity.

Both an exponential and a $r^{1/4}$ law has been adopted for the potential models of the bulge. While the photometry itself can not distinguish...
Figure 1. Photometric and dynamical features for NGC 980 with their respective best fit curves obtained from our models. (a): r-band surface brightness (open circles) as a function of radius along the major axis. We also plot the photometric components that we found (dashed lines) and the sum of these components (solid line). (b): ellipticity (open circles) associated to the upper r-band surface brightness and the best fit curve (solid line) founded. (c): observed stellar velocity (filled symbols) with its associated model (solid line), and the Hα observed gas kinematics (open symbols). The dot-dashed line is the circular velocity inferred from the model. (d): the same as (c) but for the velocity dispersion. (e): same as (c) for the $h_3$ coefficients of the Gauss-Hermite expansion of the line profile of the stars. (f): same as (c) for the $h_4$ coefficients of the Gauss-Hermite expansion of the line profile of the stars. In windows (c) to (f) the squares symbols and the triangle symbols represent data derived for the approaching NE side and for the receding SW side respectively. In window (c) due to the high values of the predicted circular velocity its fitting curve is only visible for the outer regions. The plot of the entire curve would only produce a loss of the velocity curve details.
between the two hypothesis, we found that the exponential bulge gives a better agreement with the kinematic data.

**NGC 772:** The gas seems to be pressure supported in the inner 6"; after that the rotational velocity of the gas reaches the expected circular velocity and the velocity dispersion falls to a low constant value (∼ 50 km s⁻¹).

**NGC 3898:** The stellar kinematics is well fitted by a 3-component model, including an inner flat disc coexisting with a spherical bulge of similar scale length. The gas rotational velocity is well approximated by the model circular velocity for r>8", showing no asymmetric drift.
effect, and is observed to follow a flat velocity curve out to 100″. In the inner 8″ there is a strong absorption of the Hα line, that prevent us from obtaining realistic of the velocity and the velocity dispersion.

**NGC 5064:** Apart from a slight oscillation in the ellipticity and the position angle, likely due to the spiral arms, this galaxy does not show evidence for triaxial structures or misalignments in the different stellar components. The position angle is fairly constant and there is no sign of boxy structures. Nevertheless, with the hypothesis of our models, we found that no set of parameters was able to reproduce the data. A possible explanation could be that the observed value of the rotational velocity is the mean of the superposition of different components in the central 20″ region, with different characteristic values of the rotational velocity and/or directions of the angular momentum. This possibility is supported also by the $h_3$, $h_4$ profiles which mark a strongly non-Gaussian shape of the line-of-sight velocity profiles in this region. Even inner stellar counter-rotation can not be ruled out at this moment.

5. Discussion

We analyzed the photometry and the kinematics of 5 disc galaxies (one is classified as lenticular, two as Sa and two as Sb by the RSA catalog). For 4 out of 5 galaxies, we found that an axisymmetric dynamical model can fully account for the observed stellar kinematic features, including the general behavior of the $h_3$, $h_4$ profiles. For the case of NGC 5064, models with decoupled angular momenta may be needed.

In Figs. 1-2 we present the photometric and spectroscopic data for two of these galaxies, together with the best fit models obtained. The parameters obtained from the models are presented in Table II. A sizable asymmetric drift effect is present in the inner regions of all these galaxies, as we can see by comparing the stellar rotational curves with the circular velocity predicted by the models.

The gas components show a very wide range of kinematic properties. Two of the sample galaxies (NGC 5064 and NGC 7782) show almost circular motions even very near the center; two present slowly rising rotation curves (NGC 772 and NGC 3898) and one (NGC 980) even appears to have a gas rotational curve lower in velocity than that of the stellar component.

The number of galaxies belonging to the sample is not large enough to draw general conclusions. However we have found a possible correlation between the presence of slowly-rising gas rotation curves and the ratio of the bulge/disc half luminosity radii, while there is no obvious correlation with the key parameter represented by the morphological classification, namely the bulge/disc luminosity ratio. Systems with a
diffuse dynamically hot component (bulge or lens), with scale length comparable to that of the disc are characterized by slowly rising gas rotation curves. On the other hand, in systems with a small bulge the gas follows almost circular motions, regardless of the luminosity of the bulge itself. We notice similar behavior also in the gas and stellar kinematics of two Sa galaxies (NGC 2179 and NGC 2775) modeled by Corsini et al. (1998). The application of the methods of analysis used in this contribution to a wider sample of galaxies could help us to confirm this picture.

Table II. Parameters from the Dynamical Models (I). The index $b$ and $d$ refers, respectively, to the bulge and disk component. The $d'$ index to the (eventual) third component.

| object  | scale radius | axial ratio | Mass [$10^{10} M_\odot$] |
|---------|--------------|-------------|--------------------------|
|         | $r_b$        | $r_d$       | $r_{d'}$            | $(b/a)_b$ | $(b/a)_d$ | $(b/a)_{d'}$ | $M_b$ | $M_d$ | $M_{d'}$ |
| NGC 772 | 19.0''       | 20.0''      | —                    | 0.80      | 0.1       | —            | 6.5   | 9.9   | —        |
| NGC 980 | 2.1''        | 6.5''       | 19.2''              | 0.98      | 0.2       | 0.6          | 24.0  | 4.9   | 10.0     |
| NGC 3898| 9.5''        | 6.6''       | 57.0''              | 1.00      | 0.2       | 0.3          | 3.7   | 0.5   | 3.2      |
| NGC 7782| 1.4''        | 20.1''      | —                    | 0.75      | 0.1       | —            | 6.0   | 36.0  | —        |

References

Bender, R. 1990, A&A, 229, 441
Bender, R., Saglia, R.P., Gerhard. O.E. 1994, MNRAS, 269, 785
Bertola, F., Cinzano, P., Corsini, E.M., Rix, H.-W., Zeilinger, W.W. 1995, ApJ, 448, L13
Corsini, E.M., Pizzella, A., Sarzi, M., Cinzano, P., Vega Beltrán, J.C., Funes, J.G., Bertola, F., Persic, M., Salucci, P., 1998, A&A, 342, 671
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H.G., Jr., Buta, R.J., Paturel, G., Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies. Springer-Verlag
Fillmore, J.A., Boroson, T.A., Dressler, A. 1986, ApJ, 302, 208
Gerhard, O.E., 1993, MNRAS, 265, 213
Pignatelli, E., Galletta, G., 1999, A&A, submitted
Prada, F. 1998, in Galaxy Interactions at Low and High Redshift. IAU Symposium no. 186. Kyoto, Japan, 17-30 August, 1997
Kent, S.M. 1988, AJ, 96, 514
Sandage, A., Tammann, G.A. 1981, A Revised Shapley-Ames Catalog of Bright Galaxies. Carnegie Institution, Washington (RSA)
Tully, R.B. 1988, Nearby Galaxies Catalog. Cambridge University Press, Cambridge
van der Marel, R.P., Franx, M., 1993, ApJ, 407, 525
Vega Beltrán, J.C., Pignatelli, E., Zeilinger, W.W., Pizzella, A., Corsini, E.M., Bertola, F., Beckman, J., 1999, in preparation.