THE STELLAR KINEMATICS OF SPIRAL GALAXIES WITH A BOXY/PEANUT-SHAPED BULGE

Aeree Chung and Martin Bureau
Department of Astronomy, Columbia University
email:archung@astro.columbia.edu/bureau@astro.columbia.edu

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ABSTRACT

We present the stellar kinematics of a large sample of edge-on spirals with a boxy or peanut-shaped (B/PS) bulge. B/PS bulges are known to be common among spirals (≥ 45% of all systems), and a growing body of theoretical and observational work suggests that they are the edge-on projection of thickened bars. As such, they are thought to play a central role in most bar-driven bulge secular evolution scenarios.

Long-slit spectra were obtained along the major-axis of 30 selected galaxies, 24 with a B/PS bulge, 6 with other bulge types for comparison. The line-of-sight velocity distributions (LOSVDs) were derived with the Fourier Correlation Quotient (FCQ) method and fitted with Gauss-Hermite series. Profiles of the mean stellar velocity V, the velocity dispersion σ, and the asymmetric (h_3) and symmetric (h_4) deviations from a pure Gaussian are presented. Comparing with stellar kinematic bar diagnostics from N-body simulations, we find bar signatures in 24 objects of our sample (80%). Most galaxies with a B/PS bulge show a double-hump V profile with an intermediate dip or plateau. They also frequently show a rather flat central σ profile with secondary peaks/plateaus and a central minimum. Most importantly, h_3 is normally correlated with V over the presumed bar length, unlike axisymmetric disks. These characteristic bar signatures, occurring over the extent of the B/PS bulges, strengthen the case for a close relationship between B/PS bulges and bars.

SCIENTIFIC GOAL & SAMPLE SELECTION

There are two main explanations for the structure and formation of B/PS bulges: (axisymmetric) accretion and (non-axisymmetric) bar buckling. However, the particular alignment required for accretion puts many constraints and it seems unlikely. Simulations have shown that B/PS bulges can be the edge-on projections of thickened bars in the disks of spirals. Many observational studies also support the connection between bars and B/PS bulges: in particular, a characteristic "figure-of-eight" bar signature has been found in the position-velocity diagrams of spirals with a B/PS bulge (e.g. Kuijken & Merrifield 1995; Bureau & Freeman 1999). Most of these studies, however, were done with emission-line spectra of gas-rich galaxies. Our primary goal in this study is thus to probe the absorption line stellar kinematics of a statistically significant number of galaxies with a B/PS bulge, simultaneously and independently verifying their relationship to bars. We study the 30 edge-on spirals sample of Bureau & Freeman's (1999), 24 with a B/PS bulge and 6 with other bulge types, including the 7 galaxies which showed little emission and were excluded from their study. The latter offer the best comparison with N-body models.

BAR DIAGNOSTICS

Bureau & Athanassoula (2003) developed self-consistent stellar kinematic bar diagnostics from N-body simulations of bar-unstable disks. The simulations include a luminous disk, a live dark halo, and an optional bulge component. For various viewing angles, (small) inclinations, and bar strengths, they extracted the stellar kinematics along a slit aligned with the photometric major-axis. Like most observers, they parametrized the kinematics with a Gauss-Hermite series.The characteristic bar signatures observed are numerous: i) a "double-hump" rotations curve (V); ii) a flat-top or weakly-peaked velocity dispersion profile (σ) with a secondary peak; iii) an h_3 profile correlated with V over the projected bar length; iv) an h_4 profile with central and secondary minima. These bar signatures correlate with the strength of the bar and the viewing angle (the orientation of the bar to the observer). See Figure 1.

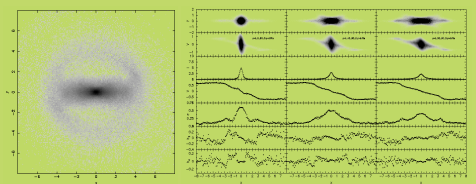

Figure 1: Example of N-body simulation. Left) Face-on view. Right) From top to bottom: edge-on view, V, σ, h_3, and h_4 profiles. From left to right: viewing angles of 0 °,45 °, 90°.

OBSERVATIONS & RESULTS

OBSERVATIONS: Spectra were obtained along the major-axis of each galaxy with the Double Beam Spectrograph of the 2.3 m telescope at Siding Spring Observatory, Australia (Dec. 95-May 97). The blue arm of the spectrograph covers about 950 Å centered on the Mg b λ5170 absorption line triplet. All galaxies were observed with a 1.8″×400″ slit and the dispersion was ≈ 0.55 Å pix^{-1}, yielding a 2-pixel spectral resolution of 64 km s^{-1}. The spatial sampling was 0.9″ pixel^{-1}.

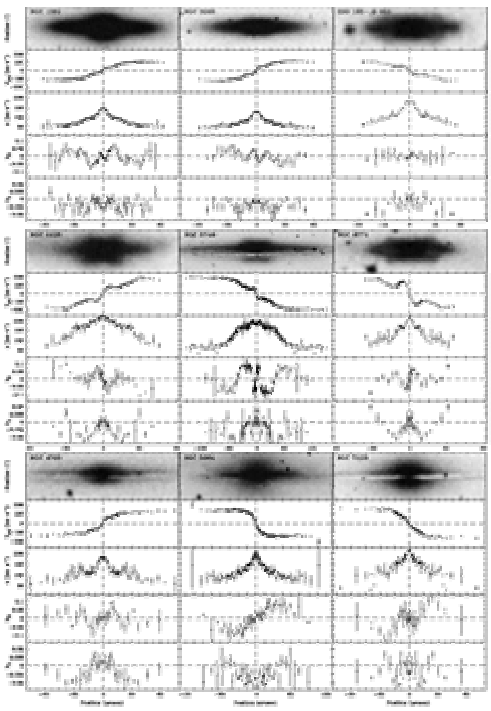

Figure 2: Stellar kinematics of selected sample galaxies with a B/PS bulge and no or confined emission (top panels), with a B/PS bulge and extended emission (middle panels), and with other bulge morphologies (bottom panels). Each panel shows an optical image of the galaxy (with isophotal contours), and the registered V, σ, h_3, and h_4 profiles along the major-axis.

DATA REDUCTION: The data were reduced using standard procedures in IRAF. The spectra were wavelength-calibrated and rebinned to a logarithmic λ (linear velocity) scale corresponding to ≈ 32 km s^{-1} pixel^{-1} over the observed wavelength range. The stellar kinematics of the galaxies was derived using the FCQ algorithm (Bender 1990) and the LOSVDs were fitted with a Gauss-Hermite series, yielding V, σ, as well as h_3 and h_4 (asymmetric and symmetric deviations from a pure Gaussian) profiles. We use the deconvolution and fitting algorithms as implemented in the XSAURON software. The results for selected galaxies are shown in Figure 2.

RESULTS

ROTATION CURVES & ASYMMETRIES

Most galaxies with a B/PS bulges display a "double-hump" rotation curve, as expected from a barred disk. Most galaxies show a rather flat V plateau at intermediate radii, while a few show merely a change of slope in the rising part of V. Only 3 of the 24 objects with a B/PS bulge do not show this feature (and 2 galaxies are obscured by dust). Most control galaxies show a featureless V, smoothly rising in the inner parts (except NGC 3957 and NGC 4703 which also show bar signatures).

Contrary to what is expected from an axisymmetric disk, h_3 is correlated with V over a large radial range in the center. According to simulations, for most of those objects (18/21) this correlation is valid only roughly within the first V plateau. But contrary to simulations, most objects show an anti-correlation of h_3 and V over a short radial range in the very center, corresponding approximately to the rapidly rising part of the V profile.

DISPERSIONS AND SYMMETRIES

A few galaxies possess a flat central σ peak with broad shoulders and small secondary peaks, as expected from a strong bar seen side-on. But most galaxies have a gently decreasing sharper central peak, sometimes showing hints of secondary maxima, as expected for weaker bars. Yet other galaxies only show a dominant, broad central peak with clear secondary peaks. The secondary peaks are usually strongest in the galaxies with double-hump V. Many σ profiles also show a central depression, i.e. a local central minimum. 10/24 galaxies with a B/PS bulge and 3/6 galaxies from the control sample have a clear local central minimum, while a few more have more marginal signatures.

h_4 profiles generally have low S/N and their measurement is somewhat affected by emission and template mismatch, so we do not discuss them.

DISCUSSIONS & CONCLUSIONS

B/PS BULGES and BARS: Most galaxies with a B/PS bulge display the stellar kinematic signatures expected from a barred disk seen edge-on: i) a double-hump rotation curve, ii) a rather flat or slightly peaked velocity dispersion profile with broad shoulders and secondary maxima, and iii) an h_3 profile correlated with V over the expected bar length. Those correlations appears to be stronger in galaxies with confined or no gas emission and confirm the relationship of bars and B/PS bulges.

INNER DISKS: Two kinematic features are not predicted by the N-body simulations: i) the correlation of h_3 with V in the very inner parts of the galaxies, and ii) the numerous local central σ minima. Both can be explained by the presence of embedded central stellar disks in the galaxies, kinematically colder than their surroundings. See Figure 3 below.

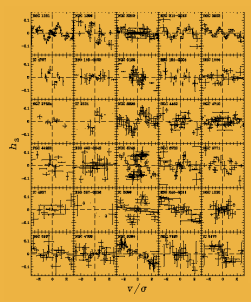

Figure 3: Velocity profile asymmetries for all sample galaxies. The skewness parameter h_3 is shown as a function of V/σ.

SECULAR EVOLUTION: Since the simulations of Bureau & Athanassoula (2003) are dissipationless, they can not reproduce any feature mainly associated with the gas (past or present). Nevertheless, our results fit nicely in a scenario where the identified central stellar disks form through bar-driven gaseous inflow and subsequent star formation, indicating that the identified bars are responsible not only of the creation of a large-scale bulge-like component out of disk material, but also of the accumulation of mass and the formation of a disk in their central region.

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