THE VELOCITY FIELDS OF ELLIPTICAL GALAXIES: CONSTRAINTS ON INTRINSIC SHAPES

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Abstract. The problem of determining the intrinsic shapes of elliptical galaxies cannot be solved using photometry alone. Measuring rotation on the apparent major and minor axes adds a kinematic constraint, but does not significantly improve the situation. We find that having two *more* spectra, at the $\pm 45°$ position angles, gives enough kinematic information that much tighter limits can be placed on the intrinsic axis ratios than are possible otherwise.

Key words: Elliptical galaxies - Radial velocities - Intrinsic shapes - Triaxiality

1. Introduction

One of the few surviving signatures, at low redshift, of the process of galaxy formation should be the distribution of shapes of elliptical galaxies. Yet the problem of inferring this distribution from the observed ellipticals is still unsolved, because insufficient use has been made of kinematic information. The kinematic data available for most ellipticals consists of only major and minor axis spectra; and Franx *et al.* (1991) find, using simple geometric models, that the addition of only one kinematic parameter (the ratio of minor axis to major axis rotation velocity) to the photometry is just not enough to finely constrain the intrinsic shape distribution. On the other hand, the more elaborate self-consistent models (*e.g.*, Levison and Richstone 1987, Statler 1987) have made only infrequent and model-dependent predictions of complicated velocity patterns, mostly at small radii, and have not discussed how they should vary with intrinsic shape.

2. Theoretical Models

We have developed (Statler 1993*a*, Paper I) an approximate but reliable method of computing the velocity field (hereafter VF) for a model elliptical of arbitrary shape. To avoid problems connected with strongly dissipative evolution in cores and the presence of central black holes, we take the view that the most useful VF features are to be found at large radii. We then assume (1) radial self-similarity at large r; (2) negligible rotation of the figure, which implies (3) intrinsic circulation (rotation) only around the long (x) and short (z) axes; (4) flow of the stellar "fluid" on spherical shells (or, with a slight added complication, on ellipsoidal shells), on which (5) the streamlines of the x and z circulations are given by coordinate lines in a confocal ellipsoidal system. This last assumption is suggested by the analytically tractable Stäckel potentials, in which the flow is exactly along those lines, but is *much less restrictive* than asserting the potential is separable. With the streamlines specified, each of the x and z flows is dictated by the equation of continuity, and the projected velocity follows with a little geometry.

A boundary condition is, of course, required to solve for the complete flow. An exact expression for the boundary condition for any one model would require knowing the complete distribution function for the tube orbits; however, we argue

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on the grounds that the mean velocity should not be spatially discontinuous, and from the existing fully self-consistent models, that the boundary condition — a function of one variable giving the mean flow across the plane containing the long and short axes — should take only a limited variety of forms. (The details of this vague statement can be found in Paper II.) We are then able to calculate VFs at any intrinsic shape and projection for a small number of ***distinguishable classes*** of models — for instance, with intrinsic streaming about the long axis, about the short axis, or about both axes. These models are distinguishable from each other because we are able to look not merely at the apparent axis of rotation (*cf.* Franx *et al.* 1991), but at the *asymmetries* of the VF, which are the true signatures of triaxiality.

3. Model Fitting

Perfect mapping of the VF is not presently feasible for any galaxy, so we ask whether a reasonable extra observational effort can give greatly improved results. We define (Statler & Fry 1993, Paper II) three dimensionless kinematic parameters (V_1, V_2, V_3) that are combinations of the velocities $(v_{\rm maj}, v_{\rm min}, v_{+45}, v_{-45})$ measured at one radius, and then average over radial bins. V_1 is essentially the "kinematic misalignment angle" used by Franx *et al.* ; V_2 and V_3 are measures of the VF asymmetry. We find that a combination of apparent ellipticity and V_2 correlates well with axis ratio c/a, and a combination of V_1 and V_3 correlates with triaxiality, for all classes of models we have tried. A Monte-Carlo modeling procedure (Statler 1993*b*, Paper III) has also been developed to fit galaxies one by one, and a preliminary application to NGC 4589 (Möllenhoff & Bender 1989) indicates that this is a prolate-triaxial system.

The intrinsic shape distribution of the full population of ellipticals is likely to be formally consistent with most types of internal streaming models, though (we would hope) different for each type. Comparing with predictions from galaxy formation theories will be necessary to settle the problem decisively, and in turn to constrain those theories.

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