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THE VELOCITY FIELDS OF ELLIPTICAL GALAXIES: STEPS TOWARD A SOLUTION OF THE INTRINSIC SHAPE PROBLEM

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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 levels of "sophistication" of the theoretical models and of the observations have up to now been poorly matched. 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 change with shape.

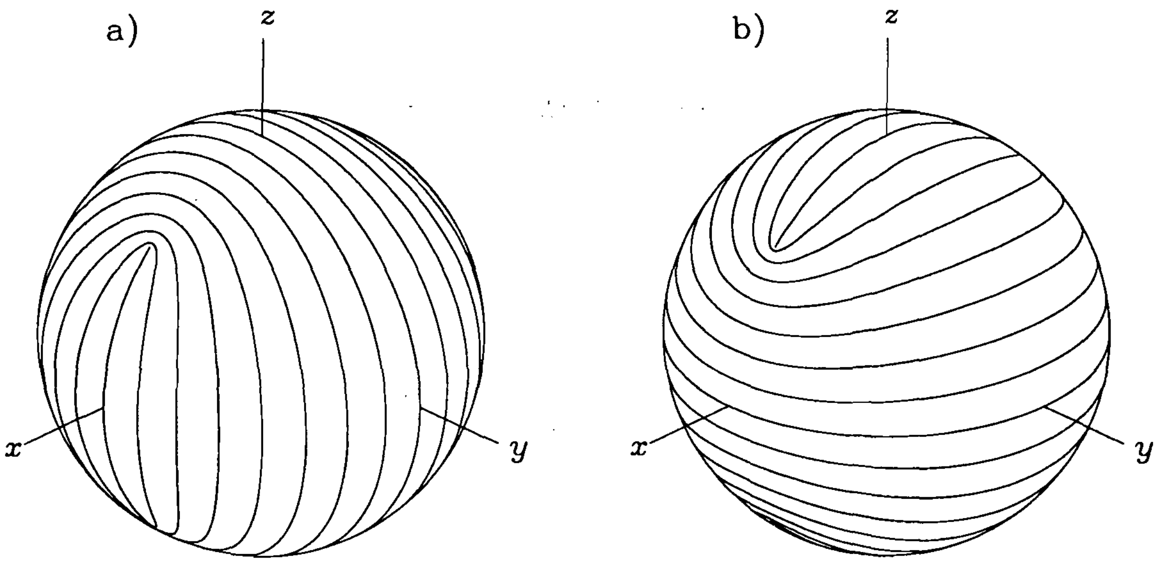

Figure 1. *Streamlines of the separate stellar flows around the (a) x axis and (b) z axis in the outer parts of a triaxial galaxy.*

Here we aim for an approximate but robust method of predicting 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, on which (5) the streamlines of the x and z circulations are given by coordinate lines in a confocal ellipsoidal system (figure 1). 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.

Of course, a boundary condition is 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 that models satisfying realistic requirements of smoothness (*e.g.*, that the mean velocity is not spatially discontinuous) will all have very similar boundary conditions. (The details of this vague statement will be published elsewhere.) 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.

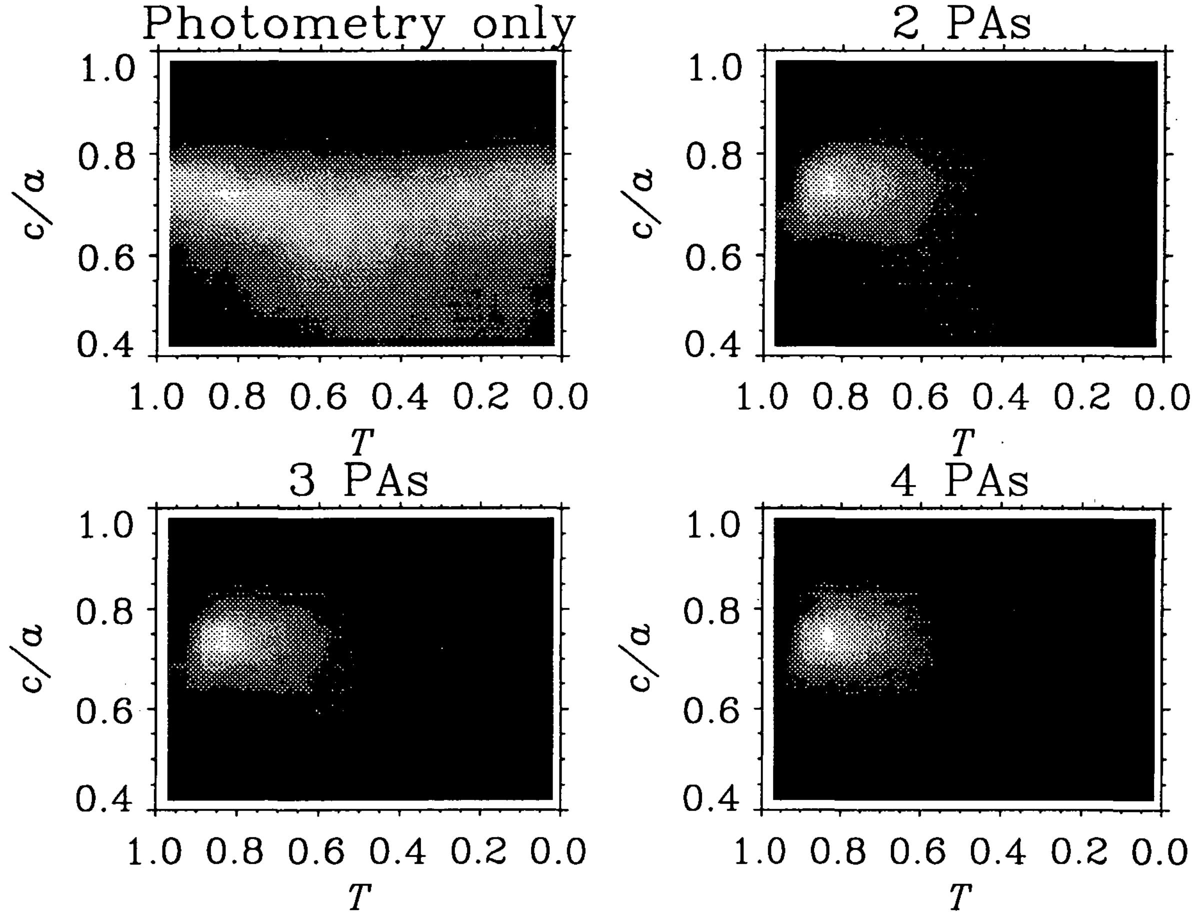

Figure 2. *Simulation showing the effect of adding kinematic constraints to the shape of a galaxy. The "observed galaxy" is E2, with large kinematic misalignment and velocity field asymmetry. Each frame shows likelihood density (goodness of fit) in the space of axis ratio c/a and triaxiality T. The benefit of of having spectra on four position angles is apparent from the two right-hand frames.*

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. Nonetheless, much can be learned immediately. Within the context of a *single* class of models, the intrinsic shape of any one galaxy can be well constrained with as few as four long-slit spectra (albeit of rather high signal-to-noise). This is shown in figure 2, where we have chosen intrinsic shapes at random and successively added constraints on the observable parameters. It is clear from frames (*b*) and (*d*) that there is much to be gained from spectra taken at $\pm 45^\circ$ from the major axis.

REFERENCES

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