'Boxy' and 'disky' isophotes

Bender 1990 in 'Dynamics & Interactions of Galaxies', ed Weilen

At ~1% level, elliptical galaxies show systematic deviations from elliptical isophotes. These can be parameterised by decomposing the isophotal profiles into higher order terms:

\[ I(\theta) = a_0 + a_2 \cos 2\theta + a_4 \cos 4\theta + \ldots \]

\[ \begin{align*}
    a_4 &= 0 \\
    a_4 &< 0 \\
    a_4 &> 0
\end{align*} \]

'pure elliptical'  
'boxy'  
'disky'
Figure 5: The radio and X-ray properties of elliptical galaxies against blue luminosity $L_B$ and isophote shape $a_4/a$. In the $\Delta L_X$ against $a_4/a$ diagram the contribution of the discrete sources to the total X-ray emission (indicated by the line in the $L_X$ against $L_B$ plot) is subtracted according to Canizares et al. (1987). $L_R$ gives the total radio luminosity at 1.4 GHz, values below $10^{21} \text{W/Hz}$ are nearly all upper limits.

(i) $a_4$ correlates with kinematic properties
(disky E's rotate faster)

(ii) $a_4$ also seems to correlate with other properties such as X-ray & radio emission
X-rays from large amounts of hot gas, DM tracer
How might you relate the result about whether an elliptical is flattened by rotation or velocity anisotropy to the boxy/disky classification?

- Very luminous ellipticals are boxy and flattened by velocity anisotropy, not rotation.
- Lower-luminosity ellipticals are disky & flattened by their rotation.

→ SAURON results suggest that these are actually disks.
Shells around ellipticals

10-20% of early-type galaxies show shells
- sharp features & faint luminosity

Interpreted as remains of infall of smaller
galaxy into elliptical’s potential well

Q Think of Kepler’s laws & orbits.
What might be causing the sharp edges
of the shells?
FIG. 4.—NGC 3923. The top picture (Fig. 4a) was made from three UK Schmidt IIIa-J plates, enhanced to show the NE shell. Scale bar is 10'. The lower pictures (Figs. 4b and 4c) were made from the same AAT plate printed through unsharp masks with different characteristics. About 18 shells can be counted. The dust cloud in Fig. 4c is real. Scale bars are 5' and 2' in Figs. 4b and 4c, respectively.

MALIN AND CARTER (see page 539)
Fig. 1.—The shells around NGC 1344. The external shells (left) are revealed by photographic amplification and subsequent superimposition of three deep IIIa-J plates taken on the 1.2 m UK Schmidt telescope. The internal shells (right) are seen by applying an unsharp masking technique to a deep IIIa-J plate taken on the AAT.

Malin and Carter (see page 538)
FIG. 1.—Time evolution of the radial, planar encounter between an exponential surface density disk and a 10 times more massive fixed and rigid isochrone potential. The cross denotes the center of the isochrone potential, and the disk is initially moving to the left. The evolution is viewed from above the orbit plane (X-Y plane), and the times indicated are in units of the circular period at a radius of one scale length in the isochrone potential. The bar under the initial time is 10 scale lengths long. The disk, as seen in the figure, is rotating in a counterclockwise sense.

FIG. 2.—Time evolution of the radial, planar encounter of an exponential surface density disk and a 100 times more massive fixed and rigid isochrone potential. Other figure parameters are as in Fig. 1.
Fig. 6—The radial velocity–radius plane for particles in the model shown in Fig. 2 at time 18. Radii are in units of the isochrone scale length, and velocities are in units of \((GM/10a)^{1/2}\).

dimensional system of test particles falling from rest into a fixed potential. The extent of the system in the field introduces a spread of energies across the system. For potentials other than the simple harmonic potential, the range in energies corresponds to a range in periods with the most bound particles having the shortest periods. Figure 5 shows the phase evolution of such a system. As time passes, the shorter period particles begin to lead the longer period ones, and the system starts to wrap in the phase plane. The wrapping proceeds at a rate determined by the range in periods present, and the number of wraps at time \(t\) after the infall begins is simply

\[ N = \frac{t}{2\pi} (\Omega_{\text{max}} - \Omega_{\text{min}}), \]

where \(\Omega\) is the radial frequency and \(\Omega_{\text{max}}\) and \(\Omega_{\text{min}}\) are the maximum and minimum frequencies present, respectively. The spatial evolution of the system can be found by projecting the phase plot onto the spatial coordinate axis. The maximum spatial excursion of each phase wrap corresponds to a sharply defined density maximum. The density maxima occur near the turnaround points of the particle orbits and propagate slowly in radius to the outermost turning point set by the least bound particle. The density maxima are therefore propagating density waves and are similar to the ring structures produced by Lynd and Toomre (1976) in their ring galaxy simulations. A similar dynamical picture has been proposed for the evolution of large-scale structure in the universe (Zel'dovich 1970; Doroshkevich et al. 1980).

Figure 6 shows the radial velocity–radius plane for the model presented in Figure 2. Here the phase wrapping nature of the shells can be clearly seen. Note also that a much larger number of shells can be detected in this way than from just the particle distribution. This is because the small number of particles used is incapable of showing all the shells at a sufficiently high contrast to be seen.

The phase wrapping interpretation of shell structures has a number of desirable features. First, the phase wraps are interleaved in radius, as has been observed for the shell galaxies. Second, the range of the number of shells present around ellipticals is a simple consequence of the age of the event. More shells will imply that a longer time has passed since the merger event, given similar rates of shells production. Shell production rates can be estimated from the range in radii of the shells and hence the spread in periods present.

The position in space of a particular shell can be calculated for a given potential by appreciating that the shells occur close to the radial turning points of the orbits. Hence

\[ \Omega_{d_m} t \approx 2\pi (\frac{m - 1}{\tau}) \]

where \(\Omega_{d_m}\) is the radial frequency of a particle with its radial turning point at radius \(d_m\), \(d_m\) is the distance of the shell from the center of the potential, \(\Theta_m\) is the orbital phase of particles with turning points at \(d_m\), and \(m\) labels the shells by the number of orbital periods completed at time \(t\) by particles in the shell at that time. The orbital phase of a particle is defined to be the time required to travel around its orbit to the nearest turning point in units of the orbital period; hence \(-0.5 \leq \Theta_m \leq 0.5\). If all the particles begin from rest, then \(\Theta_m = 0\) for all particles and \(\Omega_{d_m}(t/2\pi)\) is an integer for all shells. The variable \(m\) is the proper shell number in that it is the total number of completed periods. A second number \(n\), the observed number of shells, is defined to be

\[ n = m - \tau + 1, \]

where \(\tau\) is the total number of completed periods for particles in the outermost shell. The outermost shell is therefore labeled.
very hard to detect in late-type systems, so we do not know how universal a phenomenon they are.

A stellar system can display a sharp edge only if some parts of its phase space (see BT §4.1) are very much more densely populated with stars than neighboring parts of phase space. In the classical dynamical model of an elliptical (BT §4.4), phase space is populated very smoothly. Therefore the existence of ripples directly challenges the classical picture of ellipticals. One likely possibility is that ellipticals acquire ripples late in life as a result of accreting material from a system within which there are relatively large gradients in phase-space density. Systems with large density gradients in phase space include disk galaxies and dwarf galaxies: in a thin disk the phase-space density of stars peaks strongly around the locations of circular orbits, while in a dwarf galaxy all stars move at approximately the systemic velocity, so that there is only a small spread in velocity space.

Numerical simulations suggest that ripples can indeed form when material is accreted from either a disk galaxy or a dwarf system – see Barnes & Hernquist (1992) for a review. Moreover, simulations have successfully reproduced the interleaved property of ripples described above. Despite these successes significant uncertainties still surround the ripple phenomenon because the available simulations have important limitations, and it is not clear how probable their initial conditions are.

Schweizer et al. (1990) defined an index $\Sigma$ that quantifies the amount of fine structure such as ripples that a galaxy possesses:

$$\Sigma \equiv S + \log(1 + n) + J + B + X.$$  \hspace{1cm} (4.37)

Here $S$ measures the strength of the most prominent ripple on a scale of 0 to 3; $n$ is the number of detected ripples; $J$ is the number of optical ‘jets’; $B$ is a measure of the boxiness of the galaxy’s isophotes on a scale of 0 to 4; $X$ is 0 or 1 depending on whether the galaxy’s image shows an X structure. For a sample of 69 nearby early-type galaxies $\Sigma$ varies from 0 to 7.6. Notice that