Exponential profiles from stellar scattering off interstellar clumps and holes in dwarf galaxy discs

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ABSTRACT

Holes and clumps in the interstellar gas of dwarf irregular galaxies are gravitational scattering centers that heat field stars and change their radial and vertical distributions. Because the gas structures are extended and each stellar scattering is relatively weak, the stellar orbits remain nearly circular and the net effect accumulates slowly over time. We calculate the radial profile of scattered stars with an idealized model and find that it approaches an equilibrium shape that is exponential, similar to the observed shapes of galaxy discs. Our models treat only scattering and have no bars or spiral arms, so the results apply mostly to dwarf irregular galaxies where there are no other obvious scattering processes. Stellar scattering by gaseous perturbations slows down when the stellar population gets thicker than the gas layer. An accreting galaxy with a growing thin gas layer can form multiple stellar exponential profiles from the inside-out, preserving the remnants of each Gyr interval in a sequence of ever-lengthening and thinning stellar subdiscs.

Key words: galaxies:evolution — galaxies: kinematics and dynamics

1 INTRODUCTION

The origin of the exponential radial profile for surface brightness and mass surface density in galaxy discs is not well understood (van der Kruit & Freeman 2011). Cosmological collapse models get exponential discs without fine tun-

inner one; Pohlen & Trujillo 2006). Stars also scatter outward with bar torques (Hohl 1971; Debattista et al. 2006) forming type II (a double exponential with a steeper outer segment) or Type III exponentials (Head et al. 2015), with breaks between the two components at bar or bar+spiral resonances (Muñoz-Mateos et al. 2013; Laine et al. 2014).

- How does the disc mass know it should have an exponential form when the two parts form in different ways, the inner part by star formation with spiral and bar torques, and the outer part by radial migration? Why should both parts of the broken profiles in Types II and III be exponential, regardless of whether the stars were put there by bars, spirals, interactions, or star formation? There is something fundamental about the exponential shape in a galaxy disc.

- Here we show that large, low-density perturbations with a range of masses comparable to what is observed for interstellar clumps and holes in dIrr galaxies can make an exponential profile from a uniform initial profile in only ~ 1 Gyr.

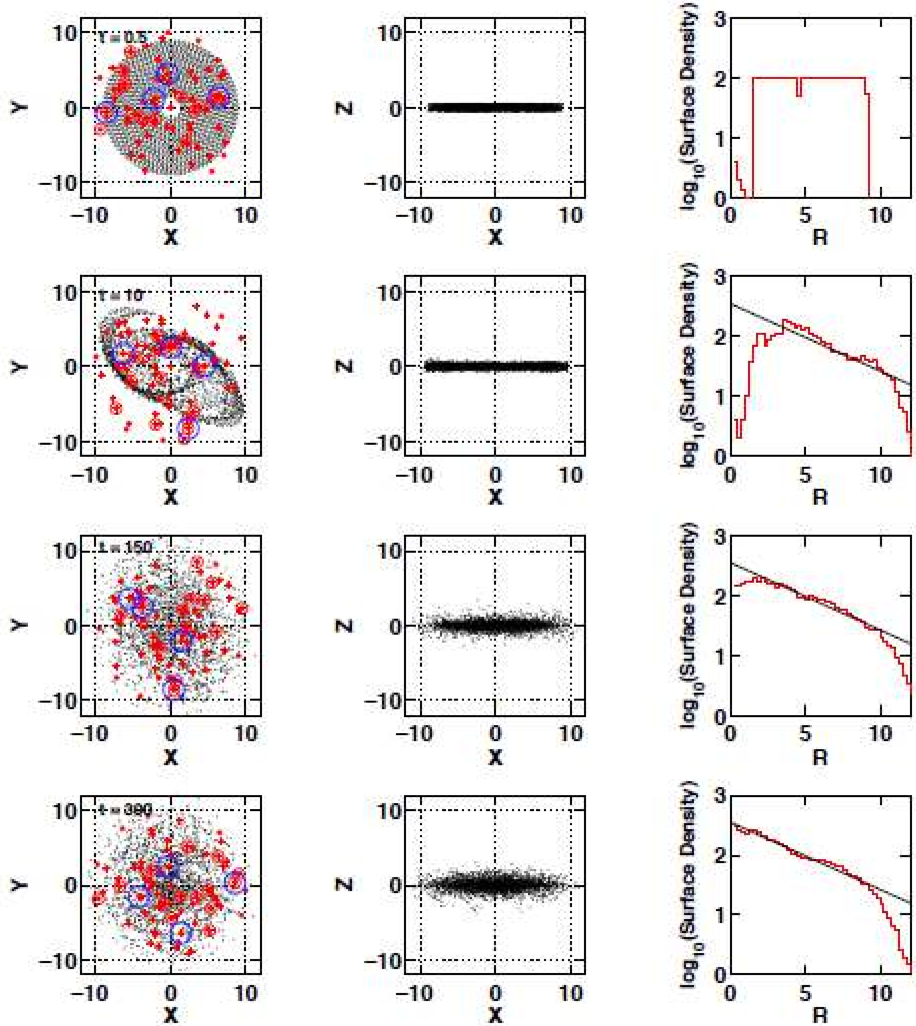

Figure 1. Four snapshots showing face-on and side views, and the development of the exponential profile in the fiducial soft clump model. Times given in simulation units of 9.8 Myr for a typical dIrr galaxy. In the first column, the red asterisks represent the smallest mass clumps, the red circles the intermediate mass clumps, and the blue circles the most massive clumps, in each case

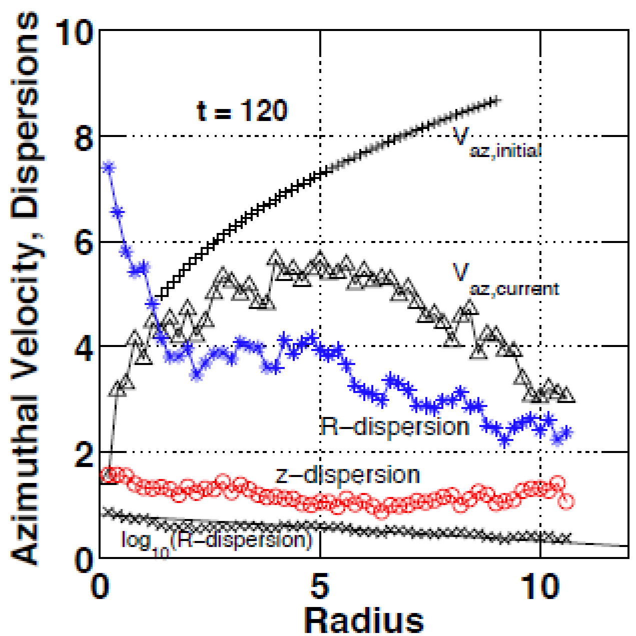

Figure 3. Velocity profiles in the clump model of Fig. 1 are shown in the top panel. The black plus signs denote the initial rotation curve given by the gravitational potential with zero velocity dispersion. The black triangles show the stellar rotation curve from actually stellar motions at a time of 120 units (~ 1.2 Gyr). Each point is the average azimuthal velocity in a radial bin of width 0.25 *units* (~ 125 *pc*). The blue asterisks and red open circles show the radial and vertical velocity dispersion profile at that time. The black x symbols show the logarithm of the radial dis-

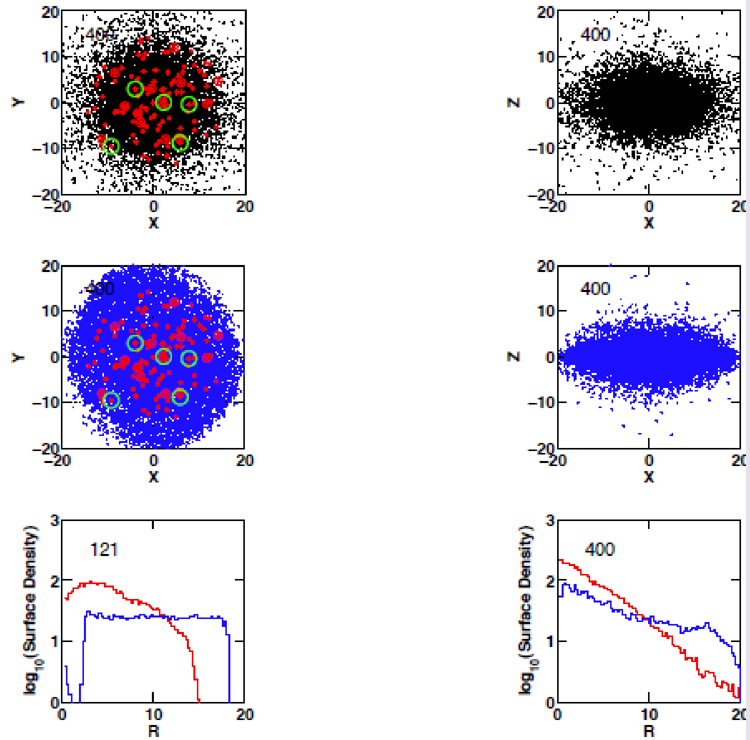

Figure 5. Model with two stellar generations The panels of th top row show the distribution of the first generation of stars a a time of 400 units (3.9Gyr) after its formation. The left pane shows the disc plane (x-y), and the right panel a perpendicula view (x-z). The panels of the second row show the same view of the second generation at the same time. This population wa introduced into the model at time of 120 units (1.2 Gyr). Th bottom panel shows the surface density profiles of the two pop ulations shortly after the younger one is introduced. The peake red curve is the old population; the flat blue curve is the younge one. The lower right panel shows the profiles of the population at the later time. The younger population is still flatter than th older one.

The thickening of the stellar disc because of scattering causes the evolution into an exponential to slow down. This implies that new stars scatter somewhat independently of old stars and make their own exponential profiles. A super-position of two exponential profiles with different ages was demonstrated.