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In What Detail Can We Represent the Milky Way in a Conventional N-Body Model?

Victor P. Debattista

Jeremiah Horrocks Institute, University of Central Lancashire, Preston, PR1 2HE, UK
email: vpdebattista@uclan.ac.uk

Abstract. After a brief review of past N-body models of the Milky Way, I consider some of the difficulties that are inherent in the N-body approach to modelling any disk galaxy.

1. Past N-Body Models of the Milky Way

Modern efforts at modelling the Milky Way (MW) take into account that it is barred. The first large effort in this regard was carried out by Fux (1997), who ran simulations of initially axisymmetric disk+bulge+halo systems. He then compared regularly spaced outputs with a de-reddened *COBE* K-band bulge map. He scaled the kinematics of his model by requiring that the velocity dispersion matches that of Baade's window. A number of models provided reasonable fits to the data. His best fit bar angle to the sun-center line, $\psi_{\rm bar} = 28° \pm 7°$. Later he added SPH gas to his simulations and was able to fit a number of features in the CO gas $l - V$ diagram Fux (1999). He argued that the high-velocity connecting arm is due to the shocked gas within the near side of the bar. The gas distribution is also sensitive to the pattern speed of the bar, and he constrained this parameter to $\Omega_b \sim 50\,{\rm km\,s^{-1}\,kpc^{-1}}$.

Widrow *et al.*, (2008) modelled the Milky Way by matching observations (including the rotation curve, local force field, Oort's constants, local and bulge velocity dispersions, surface density and total mass within 100 kpc) to a suite of *axisymmetric* models. N-body models of these then all produced bars. The time of bar formation depended on the Toomre Q and X parameters; in all cases $\Omega_{\rm p}$ started declining after the bar formed and a dynamically young bar is required if $\Omega_{\rm p} = 50\,{\rm km\,s^{-1}\,kpc^{-1}}$. A problem with this approach is, however, that bar formation leads to the model departing from the observations.

N-body models are also very useful for testing models constructing using other methods. Zhao (1996) tested his Schwarzschild model of the MW bulge using N-body simulations, finding that its shape and mass distribution is stable.

2. Fundamental Limitations

Modelling the MW, or any other disk galaxy, by N-body simulations is complicated by a number effects. Foremost, disk simulations in which a bar forms are subject to considerable stochasticity. Sellwood & Debattista (2009) show that disk simulations which differ only in the seed of the random number generator used to set up the disk particles evolve quite differently. They identified a number of sources of stochasticity, including multiple disk modes, swing-amplified noise, variations in the onset and strength of bending instabilities, metastability due to upward fluctuations in $\Omega_{\rm p}$ (Sellwood & Debattista 2006), and intrinsic chaos. Stochasticity is weaker when the halo is very massive, but is never absent. Such stochasticity makes it hard to improve N-body models by iterating runs with varying parameters.

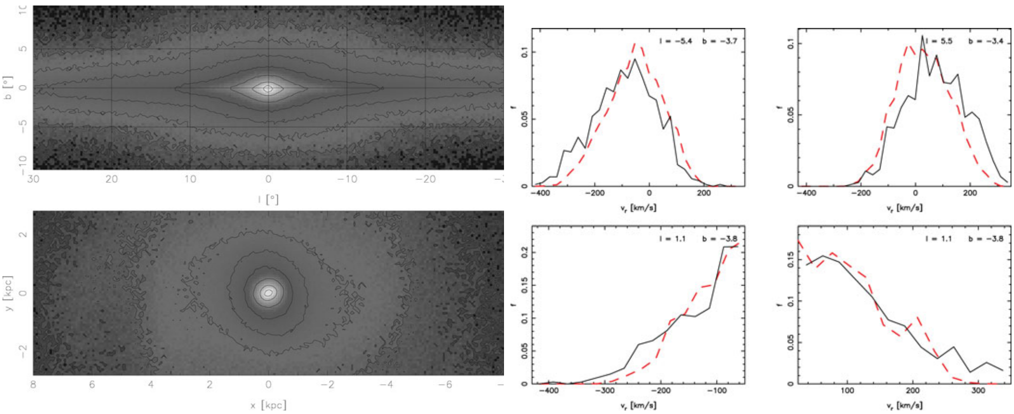

Figure 1. N-body model (left hand panels) showing the rather poor fit to the MW density. Right panels: kinematics for this model (solid lines) compared with observations (dashed lines).

Modeling is also complicated by radial migration of stars caused by transient spirals (Sellwood & Binney 2002). Roškar *et al.* (2008) show that this migration leads to significant mixing of stellar populations so that the age distribution of stars at any given radius does not reflect the star formation history at that radius. In the solar neighborhood, Roškar *et al.* (2008) estimate that as much as half the stars formed elsewhere. Since the incidence of spirals is chaotic, matching the stellar populations in simulations requires a certain degree of luck.

A third difficulty with modeling the MW is the somewhat weak constraints that kinematics of the bulge region impose on models. In order to demonstrate this, in Figure 1 I present an arbitrary disk-galaxy simulation, scaling its velocities to produce a rotation velocity of 220 km/s. The density distribution is a rather poor match to models of the MW [e.g. Bissantz & Gerhard (2002), López-Corredoira *et al.* (2005)]. However, comparing the kinematics of particles selected to lie in the bulge using selection functions that match those in observations of Rangwala *et al.* (2009) results in distributions of stellar velocities that are not substantially different from those observed.

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