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Chaos in galaxies (E. Athanassoula, M. Romero-Gómez, E. Vasiliev)

A number of papers considered various methods of determination of orbital class and degree of chaos. Most of these methods are based on the calculation of the Lyapunov characteristic exponents (LCE) and their derivatives. Skokos (2010) presents a comprehensive review of various applications of LCE. Manos et al. (2011) applied the Generalized ALignment Index (GALI) to study dynamical properties of orbits in the vicinity of a periodic orbit. Maffione et al. (2011a) focused on the MEGNO indicator (Mean Exponential Growth of Nearby Orbits) and applied it to study orbits in a triaxial galactic potential, and Maffione et al. (2011b) presented a detailed comparison of several chaos indicators, including LCE, FLI/RLI (Fast and Relative Lyapunov Indicator), GALI and MEGNO. They find that FLI/RLI are most suitable for analyzing global dynamics of the system, while MEGNO and GALI perform better at the level of individual orbits.

Among the methods not related to LCE, four-dimensional surfaces of section (SoS) were used by Katsanikas et al. (2011) in application to multiply-periodic orbits. Caranicolas & Zotos (2010) considered a potential resembling a barred galaxy and studied orbits using the S(c) spectrum, which is also a derivative of the Poincaré surfaces of section. Bountis et al. (2011) used probability distributions of sum of coordinates to distinguish weakly chaotic from strongly chaotic orbits in a potential of a barred galaxy.

Dynamical properties of spherodial galaxies and the role of chaotic orbits in their evolution were considered in several papers. Muzzio et al. (2009) studied orbital composition of triaxial cuspy galaxies formed by dissipationless collapse and found that their models have a large fraction of chaotic orbits (about 50%) and still are reasonably stable over many dynamical times. Valluri et al. (2009) studied the effect of baryonic contraction on the orbital structure of triaxial dark matter haloes and the change of shape induced by the evolution of chaotic orbits. They find that change of shape is driven mostly by a regular change in orbital class, but that chaotic scattering is important in the case of massive compact central mass. A subsequent study (Valluri et al. 2011) applied the same technique of frequency analysis for studying the shape and history of the Milky Way halo. Deibel et al. (2011) used frequency analysis to survey the orbital structure of triaxial cuspy galaxies with slow figure rotation. Vandervoort (2011) explores chaotic behaviour in a model of homologous oscillations of an axisymmmetric galaxy (whose size but not shape changes in time) and finds that oscillations with amplitude up to 40% of binding energy remain regular, while they become chaotic for larger amplitudes.

A considerable amount of work was done to establish the influence of chaos, and in particular of 'sticky' or 'confined' chaotic orbits, on the formation, properties and evolution of structures in galaxies. Manifolds, linked to the unstable periodic orbits in the vicinity of the L1 or L2, are proposed to explain both the spirals and the rings in barred galaxies. Athanassoula et al. (2009a) find that an appropriate measure of the bar strength can determine whether the morphology is that of a ring or of a spiral. In the former case the R1, R1′, R2 and R1R2 morphologies can be explained, while in the latter, a clear link between the bar strength and the spiral pitch angle is found (Athanassoula et al. 2009b) and confirmed by Martínez-García (2011). Finally, Athanassoula et al. (2010) present more comparisons to observations and give predictions for further comparisons, while Romero-Gómez et al. (2011) apply it to our Galaxy. A different approach, still based on manifolds, but relying on the apsidal sections (pericenters and apocentres) of the manifolds has been elaborated by Tsoutsis et al. (2009), Harsoula et al. (2010,

2011) and Contopoulos & Harsoula (2010) and summarised by Efthymiopoulos (2010). This second approach necessitates a bar that either does not evolve, or evolves at a much slower rate than what is necessary for the first approach, i.e. no or little secular evolution.

Patsis et al. (2009, 2010) analysed the orbital structure in NGC 3359 and 1300, using response models and making comparisons with the morphology of these galaxies. Harsoula & Kalapotharakos (2009) used frequency analysis to distinguish between regular and chaotic orbits in an N-body system and to determine the shape and percentage of orbits supporting the bar and the spiral. Manos & Athanassoula (2011) used the SALI and GALI indicators to determine the degree of chaoticity in the bar region and the effect of the bar parameters on that. They find a strong correlation between the bar strength and the fraction of orbits that is chaotic. Finally, Shevchenko (2011) gave estimates of the Lyapunov and diffusion timescales in the solar neighborhood.

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