The Automatic Galaxy Collision Software

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Abstract. The key to understanding the physical processes that occur during galaxy interactions is dynamical modeling, and especially the detailed matching of numerical models to specific systems. To make modeling interacting galaxies more efficient, we have constructed the ‘Automatic Galaxy Collision’ (AGC) code, which requires less human intervention in finding good matches to data. We present some preliminary results from this code for the well-studied system Arp 284 (NGC 7714/5), and address questions of uniqueness of solutions.

1 Introduction

Gravitational interactions and collisions between galaxies play an important role in galaxy evolution. Computer simulations of such encounters can provide detailed matches to observations of specific systems, providing information about star formation triggering and mass transfer between galaxies (Struck \& Smith 2003, hereafter SS03). However, the process of finding the best model for a particular system is time-consuming, tedious, and subjective, requiring a series of runs with the parameters being varied by hand, until the model matches the observed appearance of the galaxy, with a good match being determined by eye. Thus, only a handful of galaxy pairs have been modeled in detail. Furthermore, little information is provided about the uncertainty in the parameters or the uniqueness of the model.

To address these issues, we have created the ‘Automatic Galaxy Collisions’ (AGC) code. This code combines a galaxy interaction code with a genetic algorithm and a pattern-matching routine to automatically find models that match a particular galaxy. This modeling project is being done in parallel with a Spitzer IR and GALEX UV imaging study of three dozen nearby interacting galaxies (Smith et al. 2007, 2010a, b; Giroux et al. 2010). Our goal is to use the AGC code to produce preliminary models for our full set of galaxies. These will then be used as initial guesses for an N-body code, a method that was used in SS03.

Our approach parallels that of Theis \& Kohle (2001) and Theis \& Spinneker (2003), who used a similar method to model the NGC 4449/DDO 125 and M51 encounters. Evolutionary codes have also been used to model the M81/MS2/NGC 3077 system (Gomez et al. 2004) and the Milky Way/LMC/SMC interaction.
An alternative approach is used by Walvin et al. (2010), who are harnessing the efforts of Galaxy Zoo participants to model galaxy interactions. Another approach has been used by Barnes & Hibbard (2009), whose “Identikit” interactive graphics program provides a way for users to find a model for a particular system.

2 The Automatic Galaxy Collisions (AGC) Code

Our AGC code combines a standard restricted 3-body galaxy interaction code (Wallin 1990) with a revised and updated version of the PIKAIA genetic algorithm (Charbonneau 1995) and our own pattern-matching routine. The AGC code runs a large number of galaxy interaction simulations with randomly-selected interaction parameters. It then uses the pattern-matching routine to determine how well each model fits the observations of the galaxy system. Based on these fitnesses, it then runs a new generation of models, using parameters closer to those of the real system. Over many generations, one can converge upon a model which matches the real system very well. By using multiple runs with different initial conditions, the question of uniqueness can be investigated.

The original PIKAIA program was converted to a parallel code by Metcalfe (2001). We have re-engineered this software, repackaging and streamlining the code, improving the genetic algorithm, making the code user-friendly, and creating a test suite to validate the code.

The AGC pattern matching routine begins with a sky-subtracted smoothed image of the galaxy system being modeled. Next, for each timestep of the simulation, the model image is rotated to align the galaxy-galaxy axis with that of the real system, scaled to match the radius of the primary galaxy, and regridded to match the image. Then, a morphological chi-square is calculated for each timestep, summing over each pixel, weighting the tail and sky pixels differently from the disk regions, and scaling down the model disk points to account for dust extinction. Finally, a weighted chi-square is computed to account for differences between the model and the real kinematic line of nodes and the separation between the two model galaxies compared to that of the real galaxies. The fitness is the reciprocal of this weighted chi-square.

3 Results on NGC 7714/5

The AGC code was first tested using the interacting galaxy pair NGC 7714/5 (Figure 1a). This system has been modeled ‘by hand’ using the Wallin (1990) restricted 3-body code (Smith & Wallin 1992, hereafter SW92), and an N-body code that includes gas hydrodynamics, star formation, and ISM heating (SS03).

Over 1.5 months, we did 36 AGC runs for NGC 7714/5 with different initial random seed numbers. These runs were made on the ETSU ‘blackpearl’ computer cluster, which consists of 60 Dell 1950 blade computers. In these runs, only the 7 parameters that determine the positions, orientations, and orbits of the two galaxies were allowed to vary. The 36 runs converged to four different ‘best-fit’ models. Models W and X have retrograde orbits, while Y and Z are prograde. Models W and Z are near-head-on collisions, while X and Y are impacts near the edge of the disk. All of these models approximately match the
pair separation and basic kinematics, and all do an adequate job of reproducing the bridge. To varying degrees, each model type also reproduces the tidal tails, except for the X model, which does not match the western NGC 7714 tails well. The fact that different runs produced different ‘best’ models shows that multiple solutions are possible when the input is limited to an optical image with line of node information, and a restricted 3-body code is used. However, the quality of the best-fit models and the limited number of solutions shows that within these limitations the code works adequately, and limits the set of candidate solutions to explore further.

Of the four model types, model Z has the highest fitness and the best match to the system by eye. The results of run 16, a Z model, is shown in Figure 1b. This does a good job of producing the bridge and the long western tail. In 3-dimensional views, a long tail extends from the eastern side of NGC 7715 and curves behind NGC 7714 away from the observer. This is not visible ‘from Earth’ since it is in the same plane as the bridge and both galaxies.

While the parameters of the earlier ‘by hand’ SW92 model do not exactly match any of our four model types, it exhibits similarities to our X model, being a retrograde encounter with an off-center collision. In contrast, the ‘by hand’ SS03 hydrodynamical model most closely resembles our Z model, being a prograde near-head-on collision. In particular, both the SS03 model and our Z model produce a long eastern tail that curves back behind the bridge.

Figure 2a shows the corresponding fitness versus generation plot for run 16, showing an improvement in the fitness with increasing generation. After 61 generations, the best-fit model has a large impact parameter and no tails. By generation 97, the best-fit model had changed to an almost head-on collision. At this point, the western tail of NGC 7714 is reasonably well-matched, but the NGC 7715 tails are incorrect (Figure 2b). By the 259th generation, this discrepancy has been fixed, and the tails are aligned with the bridge.
To further test our code, we took the best-fit model from Run 16 (Figure 1b) as the ‘real’ galaxy. We then ran eight ‘rerun’ runs, with this as our ‘input image’. All 8 models converged to the same basic four model types. This shows that, within the limitations of the code, we can reproduce the basic structure of the galaxy. Rerun 6 gave us the closest match, producing a Z model that matches the Run 16 model in four of the seven parameters. The main difference is the appearance of the NGC 7715 tails, which are not lined up with the bridge.

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