NUMERICAL SIMULATIONS OF M51

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No conference on the interaction of galaxies would be complete without a contribution on M51 (NGC5194) and its companion NGC5195. Much observational and theoretical work has been carried out to try to understand this interacting pair, and to elucidate the morphological features and weak AGN which are thought to be the result of the interaction.

On the theoretical front Toomre and Toomre (1972) carried out restricted two body calculations, using mass points for 5194 and 5195 together with test particle discs. This simple calculation, involving only a few hundred particles, was surprisingly successful, generating the outer tidal tail and bridge arms, and establishing a first approximation to the orbit of 5195 around 5194. In this orbit 5195 travels in a plane highly inclined to the disc plane of 5194, going from the foreground to around behind 5194, and moving to the north as it makes one disc plane crossing 200 Myears before the time of the contemporary image.

Later, Hernquist & Barnes (Hernquist 1990) used a fully self-gravitating model, involving a bulge/halo/disc model for 5194, and distributed mass for 5195. This calculation utilized the very effective tree-code gravity method, which allows the calculation of the complex interaction to be carried out with sufficient accuracy, and confirmed the basic orbit of Toomre and Toomre. The self-gravity and higher resolution obtained from using a much greater number of particles also enabled Hernquist & Barnes to obtain well formed inner spiral structure, as well as the outer tail and bridge. However they pointed out that a better fit could be obtained to the pitch angle of the inner spiral arms, and to the degree of development of the outer southern tail, if the calculation was continued to a later time for the contemporary image than that suggested by Toomre & Toomre. On the other hand this yields a line of sight relative velocity between 5194 and 5195 which is smaller than is observed.

Recently Byrd & Salo (1995) have used a model involving gas discs in both 5194 and 5195. Their calculation involved a Finite Difference tech-

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nique for the gravity on two moving polar grids centred on the two galaxies, together with inelastic collisions for the gas particles. The greater responsiveness of the dissipative gas particles to the strongly non-axisymmetric particles yields strong spiral arms in the gas with distinct bends (similar to those observed in M51). They also proposed that the contemporary image is much later than that proposed by Toomre & Toomre, viz. 400 Myears after the first disc plane crossing. This means that 5195 (still in a highly inclined orbit) crosses the plane for a second time, and consequently at the beginning of the calculation starts in the background of M51. By this device they obtain sufficient time for the arms, bends and southern tail to develop, but also obtained the observed relative velocity between the two galaxies.

Here we report calculations using a halo/bulge/stellar disc/gas disc model for both 5194 and 5195, and using tree-code gravity and Smoothed Particle Hydrodynamics. We utilized the orbit of Hernquist & Barnes, confirming that a later time produces a better representation of the morphological features, but still having a problem with the relative velocity. The contemporary stellar and gas images are shown in figures 1 and 2, with figures 3 and 4 showing close-ups of M51. In addition we obtain some features not seen in previous calculations, but present in the observations :-

- In addition to broad stellar arms, a central bar appears in the stellar component. This has the degree of ellipticity and orientation of the major axis (in the rotational sense just behind 5195's orbit) as is observed in IR observations of the old stellar component.
- Strong narrow gas arms, with the observed distinct bends, and resolved shocks in the inner side of the arms, in agreement with CO observations.
- A nuclear gas ring - although with a radius half the size of the one observed.
- Warping on the outer disc and tail leading to apparent counter-rotation as viewed along the line of sight.

These features, we believe, are not highly sensitive to minor modifications of the orbit, and are likely to persist if we use the modified orbit of Byrd & Salo. They demonstrate conclusively that the major morphological features of M51, even at its centre, are dictated by the dynamics of the interaction with 5195.

References

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Hernquist, L. 1990. Heidelberg Conference on Dynamics & Interactions of Galaxies 108
Toomre, A., & Toomre, J. 1972. Ap.J. 178 623

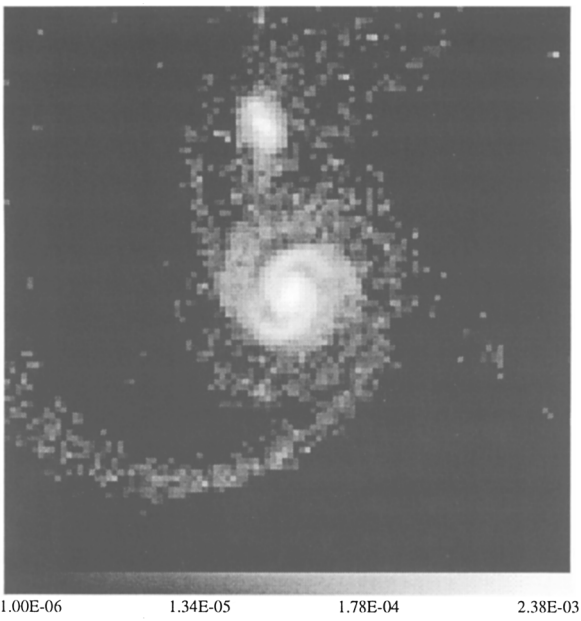

Figure 1. Stellar image of the 5194/5195 pair.

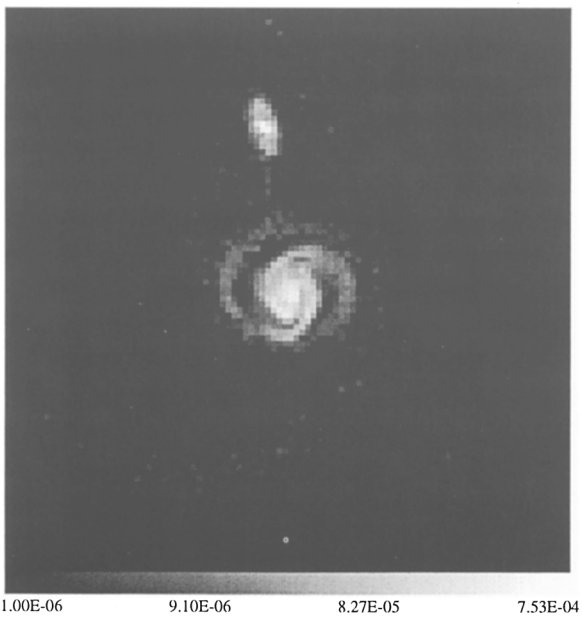

Figure 2. Gas image of the 5194/5195 pair.

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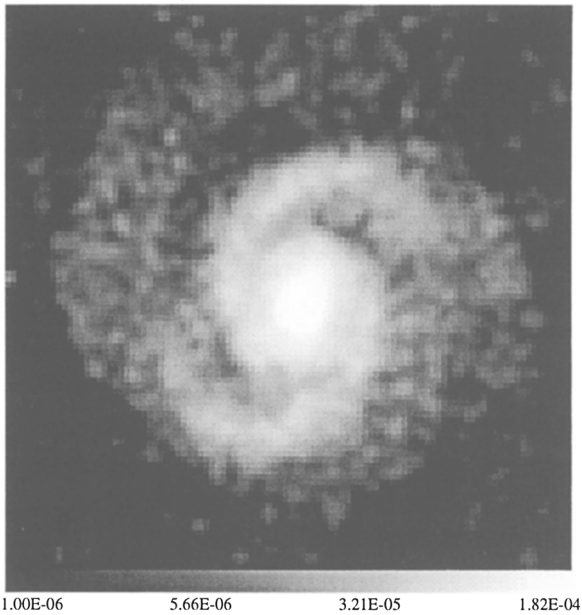

Figure 3. Close up of the Stellar image of M51.

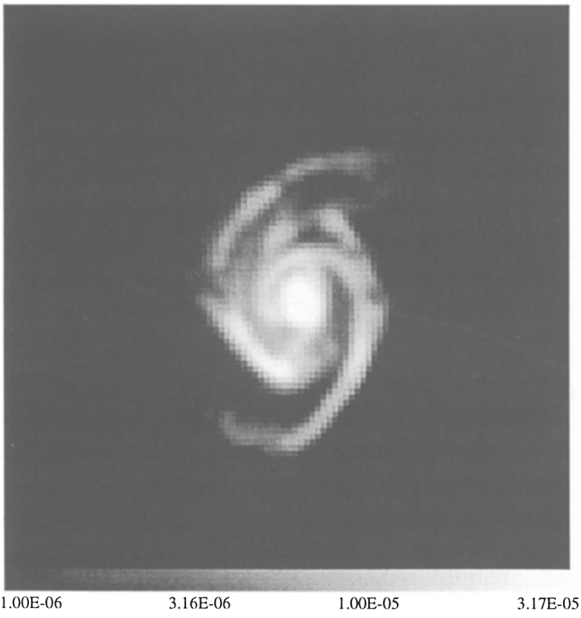

Figure 4. Close up of the Gas image of M51.

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