NUMERICAL SIMULATIONS OF FISSION

R. H. DURISEN, S. YANG, and R. GRABHORN
Department of Astronomy
Swain Hall West 319
Indiana University
Bloomington, IN 47405
U.S.A.

ABSTRACT. Recent hydrodynamic simulations indicate that gravitational torques due to spirals arms suppress binary fission in rapidly rotating polytropic fluids.

1. Introduction

Self-gravitating equilibrium states of rotating fluids are subject to a variety of secular and dynamic instabilities and bifurcations. Many scenarios have been suggested whereby evolution through these instabilities or bifurcations might produce a binary or multiple body system from a single body by growth of nonaxisymmetric distortions. I will refer to this hypothetical process as "binary fission".

2. Numerical Simulations

2.1. METHODS

In recent years, numerical hydrodynamic simulations in three dimensions have been used to explore the regime where axisymmetric equilibrium states are known to be dynamically unstable to barlike distortions. Contributions can be distinguished by the polytropic index n of the fluids considered and by the nature of the numerical hydrodynamics scheme, either smoothed particle (SPH) or finite difference (FD): n = 3/2, FD and SPH (Tohline et al. 1985, Durisen et al. 1986); n = 1/2 and 3/2, SPH (Durisen and Gingold 1986); n = 0.8 to 1.8, FD (Williams and Tohline 1987, 1988); n = infinity (isothermal), SPH (Miyama et al. 1988). In all these studies, axisymmetric equilibrium models with small nonaxisymmetric perturbations are loaded into the hydro codes as initial conditions.

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2.2 EXAMPLE

Figure 1 illustrates two stages from an evolution with $n = 3/2$. The rotation parameter $T/|W|$ is 0.33 initially, where T is the rotational kinetic energy and W is the gravitational potential energy. By 2.5 rotations, the initial seed bar perturbation has grown into a two-armed spiral, and the central region has almost undergone binary fission. The binary never pinches off, however, because the outer spirals exert gravitational torques which extract orbital angular momentum. A short while later the lumps of the protobinary crash together to form a stable, barlike equilibrium which resembles a Riemann S-type ellipsoid. The final state is a detached ring and disk of material surrounding the central bar. The gap between the bar and ring is the position of orbital corotation with the tumbling bar.

2.3 GENERAL RESULTS

From $n = 1/2$ to infinity, independent of code and initial perturbation, simulations exhibit the following common features: 1.) Two-armed spirals grow dynamically near and above $T/|W| \approx 0.27$, in agreement with classic bar mode results when $n = 0$. 2.) The trailing spirals transport angular momentum outward and suppress binary formation. 3.) As n increases for fixed $T/|W|$, more mass and angular momentum are ejected, and the central regions experience more significant contraction. 4.) As $T/|W|$ increases for fixed n, higher order structure and more long-lived binary fragments can appear.

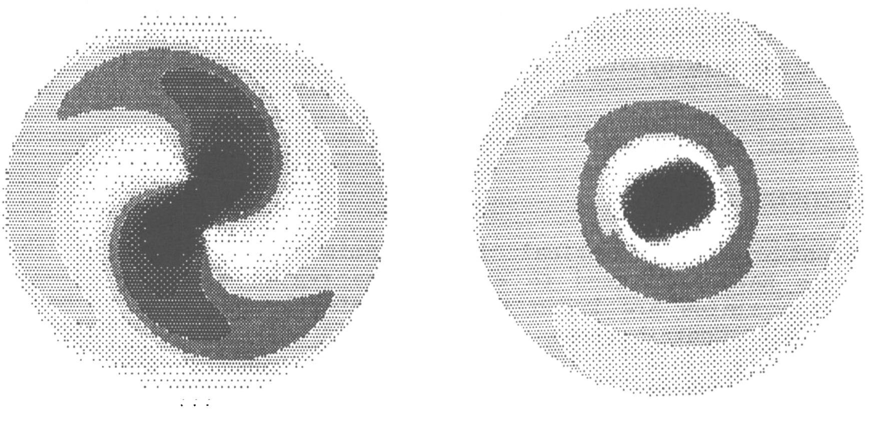

Figure 1. Grey scale representations of the density in the equatorial plane for an $n = 3/2$, $T/|W| = 0.33$ polytrope. Black signifies the highest densities, and white denotes essentially zero density. The fluid rotates in a clockwise sense. The left and right panels corresponds to about 2.5 and 5.0 central initial rotation periods, respectively.

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3. Implications

The simulations to date all produce a form of fission, in that a ring or disk of material is ejected, but "binary" fission is generally suppressed by gravitational torques. Unfortunately, the finitely unstable initial equilibrium conditions of these simulations are not physically realistic. All binary fission scenarios involve slow evolution in equilibrium from stable conditions toward and through an instability or bifurcation point. Simulations of this type are currently being pursued. However, a simple physical argument suggests that "binary" fission will still be suppressed. Sufficiently rapid rotation to induce instability and bifurcation requires differential rotation for $n > 0.8$. It is differential rotation that induces the trailing spiral arms and consequent torques. This seems difficult to escape for ordinary stellar compressibilities ($n \geq 3/2$).

The investigations reported here use centrally condensed configurations with similar angular momentum distributions. Studies are now underway by various groups to explore a wider variety of equilibrium models, including tori and protostars. Preliminary results indicate significant differences in stability properties.

Although it is becoming clear on observational grounds that low mass stars rotate too slowly to fission during pre-main sequence contraction, fission instabilities may well play an important role during the protostellar accretion phase, when rapidly rotating equilibrium states of various sizes and forms can be expected to occur.

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