Movies
Produced by LSU's Astrophysics Theory Group

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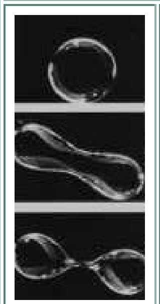
The research results being briefly summarized on this page also have been featured in an article entitled, "Splitting Stars in Binary Systems" that appeared in the April-June, 1999 issue of ENVISION, a quarterly science magazine published by the NPACI (National Partnership for Advanced Computational Infrastructure) and the San Diego Supercomputing Center.

The Fission Mechanism for Binary Star Formation
[1998 - 1999]

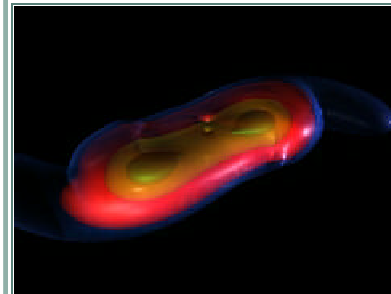
In an accompanying report, we have shown how nonlinear computational fluid dynamics techniques can be used to construct dynamically stable models of rapidly rotating, self-gravitating, *compressible* gas clouds that are triaxial (bar-like) in shape, and that have nontrivial internal motions. For all practical purposes, the models we have been able to construct appear to be compressible analogs of Riemann ellipsoids (CAREs).

Rotating Fluid Drop



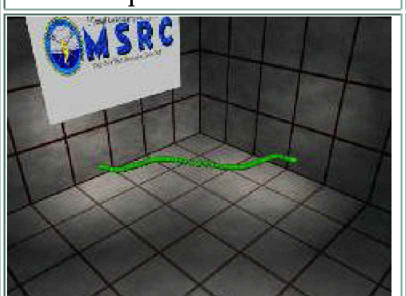
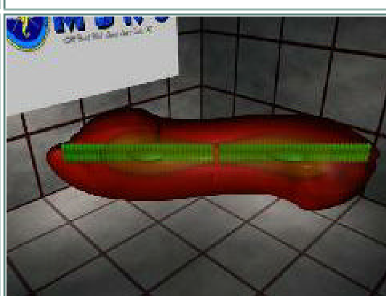
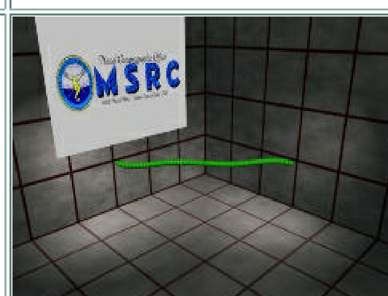
Results from a 1992 space shuttle (STS-50) Drop Dynamics Experiment.

In the context of the evolution of protostellar gas clouds, it has been suggested in the past (see, for example, Lebovitz 1988) that the slow (Kelvin-Helmholtz) contraction of such structures may lead in a very natural way to the formation of binary stars through a process of "fission." In a qualitative sense, this fission mechanism is envisioned to be similar to the process by which a drop of fluid breaks into two roughly equal pieces if it is enduced to spin rapidly enough. (See the inset images from a microgravity laboratory [USML-1] experiment performed on the space shuttle.) In an effort to test this important hypothesis, we have slowly cooled one of the dynamically stable CARE models from our earlier study (specifically, Model A), continuously following the model's dynamical flow in a self-consistent fashion throughout this evolutionary cooling phase (Cazes 1999). We cooled the model by reducing the gas pressure at a steady rate uniformly throughout the model; we chose to cool the model at a rate that would have reduced a spherically symmetric cloud to half its initial radius in 32 dynamical times. Although this rate of cooling is much faster than would be expected during the Kelvin-Helmholtz contraction phase of a real protostellar gas cloud, it was slow enough to permit the contraction to occur in a quasi-static fashion (*i.e.*, the model remained in good virial balance throughout the cooling evolution) yet fast enough to permit us to complete the simulation without demanding an unreasonable amount of high-performance computing resources.

Cooling Evolution

Quicktime (8,514K)

The animation sequence labeled here as "Cooling Evolution" shows the behavior of the model during the last segment of this slow cooling evolution. (Note that the evolution is being followed from a frame of reference that is rotating with the fluid's overall rotational pattern frequency, so the cloud's coherent spinning motion has been suppressed.) As the movie shows, the cloud does eventually contract to a stage where a pair of off-axis density maxima and, hence, a binary configuration, arises spontaneously. At the very end of this animation sequence, we stopped cooling the cloud in order to determine, at that particular point in the evolution, which configuration -- the centrally condensed bar-like structure or the binary state -- happened to represent the absolute minimum energy state. In response to this query, the system settles back into the bar-like configuration. But through this investigation we have successfully demonstrated for the first time that a binary configuration *does* become available to the slowly contracting gas cloud as hypothesized by Lebovitz (1988), and we are quite confident that, if the cooling were continued *and* we were able to maintain adequate spatial resolution to accurately follow the cloud's continued radial contraction, the system would eventually settle into the binary equilibrium state.

In the left two animation sequences labeled here as "Internal Flow," we illustrate the differential internal motions that were present in our fluid system at the times during the cooling evolution that it was in the "binary" state. In the first frame of the "Equatorial Flow" movie, a group of test particles has been lined up along the major axis of the configuration. In the first frame of the "Meridional Flow" movie, a vertical *sheet* of test particles has been aligned with the major axis of the system. Thereafter the particles are followed as they move along streamlines of the flow, as viewed in a frame of reference that is rotating with the overall pattern speed (orbital period) of the system.

Internal Flow		
Equatorial Flow	Meridional Flow	Andalib Model
		
Quicktime (5.75M)	Quicktime (3,375K)	Quicktime (5,725K)

Notice that there is a component of the flow that is *around* each off-axis density maximum, as one would expect in a realistic binary star system. A portion of the flow that can be identified with the system's "common envelope" continues to stream along the edge of the system, flowing around both density maxima. Note the strong similarities between the equatorial flow that has developed in the binary configuration that has developed spontaneously in our nonlinear dynamical simulation and the flow that appears in Andalib's "dumbbell" model (also shown and discussed elsewhere) that Andalib (1998) has constructed using a self-consistent-field technique.

References

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  " *The Formation of Common-Envelope, Pre-Main-Sequence Binary Stars* "

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This work has been supported, in part, by the U.S. National Science Foundation through grant AST-9528424 and, in part, by grants of high-performance-computing time at the San Diego Supercomputer Center and through the PET program of the NAVOCEANO DoD Major Shared Resource Center in Stennis, MS.

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