3D SIMULATION OF INTERSTELLAR CLOUD COLLISION AND TRIGGERED STAR FORMATION

Mikio Nagasawa, Shoken M. Miyama
Department of Physics, Kyoto University, Kyoto 606, Japan

Cloud-cloud collision has been regarded as one of the important mechanisms which triggers star formation. But a detailed analysis on the change of the critical mass has been absent due to the poor resolution of numerical experiments or limited by the assumption of a geometrical symmetry. We simulate the collisions between isothermal interstellar clouds using a three-dimensional hydrodynamic code (Smoothed Particle Method). The simulation in three dimensions gives us not only the criterion for the trigger of star formation but also the information about the origin of the interstellar cloud rotation and its initial distribution of angular momentum.

1. HEAD-ON COLLISION

Our initial conditions involve two spheres which are in the hydrostatic equilibrium. The investigations are carried out changing impact Mach number and total mass. In the collision of identical clouds, the shock compressed layer can be formed and the central density increases by the square of the impact Mach number (see Figure 1). As the result of this density enhancement, the collapse can set in even if the total mass of the system is smaller than Bonner-Ebert critical mass

$$M_{cr} = 1.18\ (C_s^8/G^3\ P_e)^{\frac{1}{2}} ,$$

where C_s is the cloud sound velocity and P_e is the external pressure exerted on the cloud surface. Therefore, two stable isothermal clouds of $M \geqq 0.4\ M_{cr}$ can become unstable if they experience a supersonic head-on collision. But the efficiency of this triggering mechanism cannot increase for the high Mach number collision because of the saturation of gravity in the disk geometry.

In our simulation of an isothermal gas cloud, disruption or fragmentation by a head-on collision is less likely. In the case of a stable collision, two clouds merge and repeat oblate-prolate oscillation until they get a new hydrostatic equilibrium (see Figure 2). While in the case of triggered star formation, the central part (about 30% of the total mass) begins to collapse.

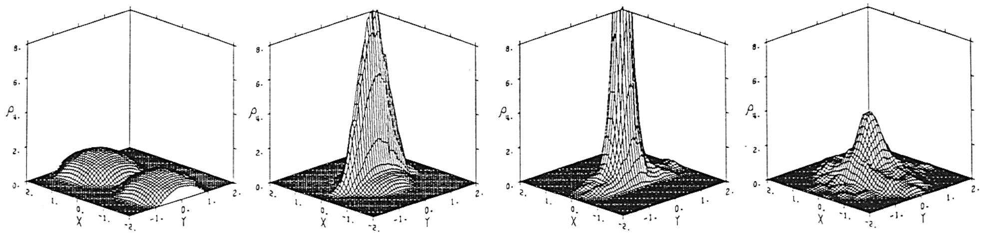

Fig. 1. Density distribution on the X-Y plane at the typical stage of stable head-on collision. In this model the collision occurs along the X-axis with the velocity $V = 3\ C_s$ and each cloud has a mass $M = 0.39\ M_{cr}$.

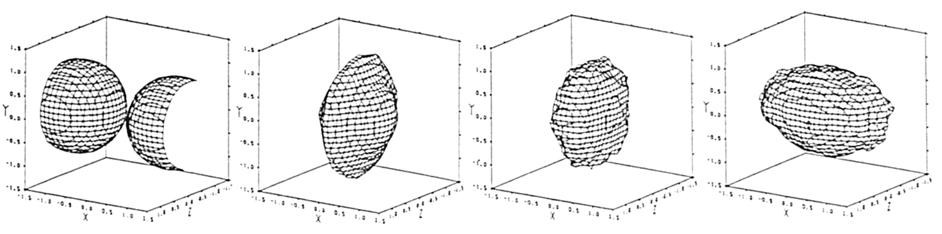

Fig. 2. Evolution of the equidensity contours for the same model shown in Figure 1. Oblate-prolate oscillations continue until it achieves a new hydrostatic equilibrium.

2. OFF-CENTER COLLISION

The off-center collisions result in various fascinating configurations such as a filamentary structure by the tidal effect or two orthogonal disks due to shock compression and rotation. These structures are very suggestive for the interpretation of observed cloud morphology.

KLEIN: I have recently performed with my collaborators similar cloud-cloud collisions in 2 spatial dimensions. Our calculations include

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cooling, and it is demonstrated that cooling leads to instability and fragmentation of the dense disk that is formed. This disruptive fragmentation is not seen for purely isothermal calculations unless a very low-isothermal temperature is picked. I would caution against interpreting pure isothermal calculations. Cooling should be included (Hunter,Sandford, Whitaker and Klein; Astrophys. J. 1986).

ON EARLY EVOLUTION OF ACCRETING STARS

B.M. Shustov, A.V. Tutukov
Astronomical Council of the USSR Academy of Sciences,
Moscow, USSR

Accretion is a dominant factor in the early evolution of stars. The first time an accretion regime settles in is when a dusty opaque core forms. The mass of adiabatically contracting core inside the isothermally collapsing envelope depends only on the optical properties of dust. Spherically symmetric models of dusty cores were constructed using the Henyey technique with accretion boundary conditions (Menshchikov 1986). It appears that all protostars with normal chemical composition should pass through the stage of a quasistatic dusty core. The evolution of dusty cores is similar to that of "normal" young stars with accretion. One could distinguish convective, radiative and central core contraction phases. The life-time t_c of the core depends on the core mass M_c and the accretion rate $\dot{M}$ (for $M_c = 0.01\ M_\odot$ and $\dot{M} = 1.6\times10^{-6}$, $1.6\times10^{-5}\ M_\odot$/year $t_c = 1.2\times10^4$, 3×10^3 yrs consequently). After dust exhaustion in the core it collapses and a central ionized quasistatic region grows in several tens of years. A flash of infrared radiation at the moment is not excluded.

According to numerical models (Tutukov and Shustov 1981) $\dot{M}$ is nearly constant during the main accretion phase (time scale t_a(yrs) $\sim 3\times10^5\ M/M_\odot$ for a cold cloud) and it stops abruptly in a time shorter than t_a. This abrupt cessation of accretion is one of the reasons for the so-called "birthline" in the H-R diagram.

The evolution of accreting stars ($0.1<M/M_\odot<6.0$) assuming constant $\dot{M} = 3\times10^{-6}$ and $10^{-5}\ M_\odot$/year was calculated by Tutukov and Chiefi (1985). The major problem concerns the fate of the energy liberated at the shock front. Two limiting cases are: a) almost all the energy liberated at the shock front is lost outward and the accreted matter therefore has low entropy, b) almost all the energy goes into the star. Evolutionary tracks of accreting stars (solid lines), tracks after cessation of accretion (dashed lines) and the "birthline" (zigzag line) are shown in Figure 1. The location of the tracks for models with accretion is insensitive to the exact value of $\dot{M}$. More important is the relation between t_a and the thermal time scale t_{KH}. The turnover point in the tracks for case b) means that t_{KH} becomes smaller than t_a.