Criteria for Collapse and Fragmentation of Rotating Clouds

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ABSTRACT. Three dimensional computations for processes of collapse and fragmentation of rotating gases are performed and criteria for fragmentation of rotating clouds in the cases of the various equation of state are obtained.

We are considering formation processes of stars in binaries and multiple systems. As one of these processes, we are studying fragmentation processes of rotating clouds or adiabatic cloud-cores. Using three-dimensional numerical computations, we obtain the criteria for fragmentation of rotating clouds.

In order to concentrate our attention on physics of fragmentation processes, we make the following assumptions and simplifications. The equation of state (EOS) is assumed to be polytropic as $P = K\rho^{\gamma}$, where K and γ are a constant number and the adiabatic constant, respectively. The initial state of a rotating cloud is assumed to be a spherical gas with uniform density ρ_0 and constant angular velocity Ω_0, but there are small and random density perturbations, $\Delta\rho/\rho \leq 0.03$.

From above assumptions, the initial state of a cloud is parameterized by two nondimensional parameters as $\alpha_0 = T/|W_g|$ and $\beta_0 = E_k/|W_g|$ where T, E_k and W_g are thermal energy, rotational energy and gravitational energy, respectively.

We summarize the computational results in the case of $\gamma = 7/5$ in Figure 1, where at the position of the initial state in the $\alpha_0 - \beta_0$ plane, we plot the final stage of the computations. In this figure, we understand easily the dependence of the final state on the initial α_0 and β_0. In this case, in the low α_0-valued and high β_0-valued region in the $\alpha_0 - \beta_0$ plane the initial model fragments into pieces. In the higher α_0-valued region, the cloud does not fragment but a spiral mode appears. In the more upper region, the cloud only shrinks and the nonaxisymmetric mode does not appear. The final stages of the computations depend also on the value of β_0. The computations are performed in the cases of other EOS. We find that in the gases with $\gamma > 4/3$, as the initial value of β_0 becomes larger, the fragmentation occurs more easily. This dependence on β_0 is very different from the cases of isothermal collapse (Miyama, Hayashi and Narita, 1984)

In order to interpret the numerical results, we estimate the flatness of a rotating disk formed in a collapsed gas. Then using the stability analysis of the rotating infinite sheet, we obtain the criterion of fragmentation. Hence if the flatness of the disk is greater than some value, say 4π, the disk is assumed to be unstable

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 127–128.

for fragmentation. It is to be noticed that the value 4π is determined because in the isothermal sheet the growth rate is largest at that value for any angular velocity as long as the system is unstable and this value depends weakly on the EOS. Then, we obtain the criteria for fragmentation as $\alpha_0\beta_0^{4-3\gamma} = constant$. For typical value of γ, they are $\alpha_0 = 0.064\beta_0(\gamma = 5/3)$, $\alpha_0 = 0.090\beta_0^{1/5}(\gamma = 7/5)$, $\alpha_0 = 0.098(\gamma = 4/3)$ and $\alpha_0 = 0.15\beta_0^{-1}(\gamma = 1)$. These criteria agree the numerical results well. Especially the difference of the critical curves between the cases of $\gamma > 4/3$ and $\gamma < 4/3$ is well interpreted by this criteria.

Then the quantity $\alpha_0\beta_0^{4-3\gamma}$ is a very important value to determine the evolution of a rotating cloud. In the case of isothermal clouds, this value is proportional to square of c_sJ/GM^2 (c_s, M and J are sound velocity, the total mass and the total angular momentum) and in the case of adiabatic gases, this value is also described only by the constants of motion (in this case, entropy, J and M). Hence, we consider the criterion obtained here are applicable to the general initial data, because that quantity is very fundamental for rotating gases.

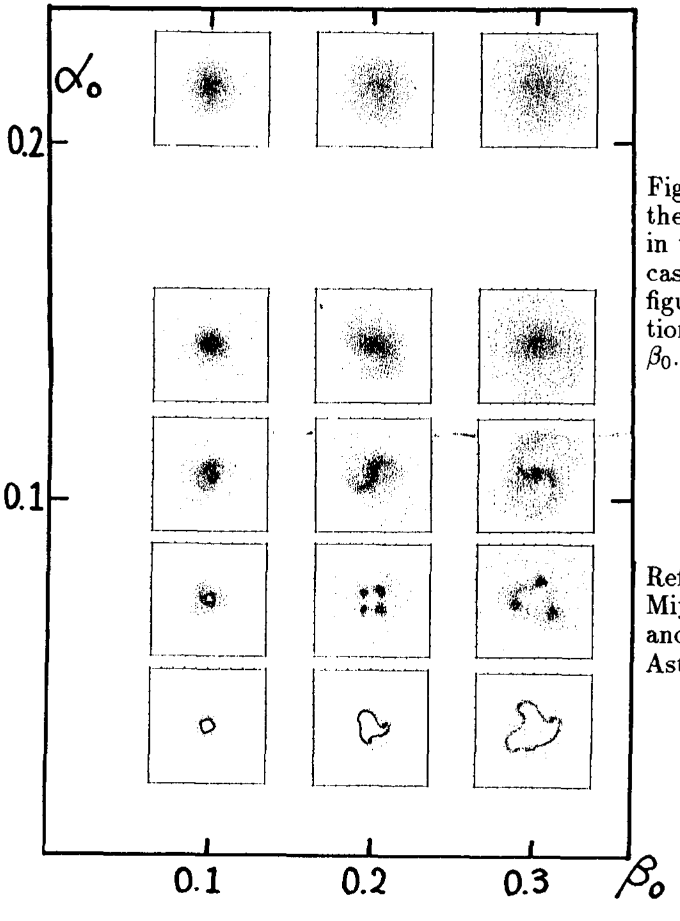

Figure 1. The final stage of the adiabatic rotating gas in the $\alpha_0 - \beta_0$ plane in the case of $\gamma = 7/5$. The each figure is shown at the position of the value of α_0 and β_0.

Reference
Miyama, S.M., Hayashi, C. and Narita, S. (1984) Astrophys. J. **279** 621.

https://doi.org/10.1017/S1539299600007590 Published online by Cambridge University Press