GRAVITATIONAL INSTABILITY OF ROTATING GASEOUS DISKS WITH MAGNETIC FIELDS

Takashi Nakamura, Takuji Iwata
Department of Physics, Kyoto University, Kyoto, Japan

The gravitational instabilities are investigated for rigidly rotating isothermal gaseous disks with a magnetic field whose mean direction is parallel (case A) and perpendicular (case B) to the rotation axis. The linearized equation for the perturbation becomes an eigen value problem which is solved numerically. The stability depends on two non-dimensional parameters $p^2 \equiv B_0^2/(4\pi^2 G\sigma_0^2)$ and $q^2 \equiv \Omega_0^2/(\pi G\rho_{0_c})$ where B_0, σ_0, Ω_0 and ρ_{0_c} are the magnetic field strength, the column density of the disk, the uniform angular velocity and the central density, respectively.

In case A, it is found that the effect of the magnetic field and that of rotation are co-operative. In case B, the stability depends not only on p^2 and q^2 but also on the direction of the wave vector of the perturbation. When the wave vector is parallel to the magnetic field, the disk is always unstable and the growth rate increases as a function of p^2 for a fixed q^2. This means, contrary to case A, that the effect of magnetic field and that of rotation are not co-operative, which is physically due to the suppression of the stabilizing effect of Coriolis force by the magnetic field.

FORMATION OF OB STARS BY RADIATIVELY-DRIVEN IMPLOSION

R.I. Klein
UC, Lawrence Livermore Natl. Lab., Livermore, CA 94550 USA
C.F. McKee
Phys. Dept. UC, Berkeley,CA 94720 USA
M.T. Sandford, R. Whitaker
Los Alamos Natl. Lab., Los Alamos, NM 87545 USA
P.T.P. Ho
Dept. of Astron. Harvard University, Cambridge, MA 02138 USA

1. THEORETICAL MODELS FOR RADIATIVELY-DRIVEN IMPLOSION

A theory for the sequential formation of OB stars in dense molecular clouds was first quantitatively investigated by Elmegreen and Lada (1976). The model was one-dimensional in nature and assumed shock propagation into homogeneous clouds. This picture has provided a successful explanation of the morphology of the Ori OB1 association.

We now know from observations (Stark and Blitz 1978) that giant molecular clouds exist in a myriad of irregular shapes and structures,

https://doi.org/10.1017/S0074180900096145 Published online by Cambridge University Press

and observations in recent years have yielded increasing evidence that these clouds are highly non-uniform, possessing clumps down to size scales of a few × .01 pc, the limit of our present resolution capability. Given that molecular clouds are clearly not uniform, a key question that arises is: "What are the consequences for star formation of the dynamical evolution of ionization-shock fronts in *inhomogeneous molecular clouds?*" This question has been pursued over the past few years in a series of detailed time-dependent, two-dimensional, radiation-hydrodynamic, two-phase flow calculations whereby one or more O stars generate multi-dimensional ionization fronts that irradiate cloud clumps in close proximity to the O stars and propagate shockwaves into the clump matter (Klein, Sandford, and Whitaker 1983, 1985, and references therein).

The first calculations in this series investigated the mechanism of radiation-driven implosion of clumps by single O stars. The pressure behind an ionization front of finite curvature is substantially greater than that behind a planar front because of the reduced attenuation of the ionizing radiation. Convergence of the resulting shock further increases the pressure. These highly compressed clumps, if massive enough, become gravitationally unstable and form new stars on substantially shorter time scales than required by the Elmegreen-Lada mechamism. Less massive clumps would either photo-evaporate or become Bok-type globules. Thus, the morphological structure surrounding a cluster of O stars may significantly influence the subsequent star formation in the cloud interior. The results of these and subsequent calculations illustrated the great efficiency of radiation-driven implosion and led Klein *et al.* (1983,1985) to conclude that two or more O stars in a cloud could successively implode a region of embedded clumps in a hierarchical sequence leading to the rapid formation of an OB cluster in a few $\times 10^4$ years with separation distances of $\sim$ 0.1 pc between newly formed stars.

2. NEW OBSERVATIONS OF OB CLUSTERS

Recently, new high dynamic range (1000-2000), radio-continuum maps, in addition to NH_3 maps, were obtained for two regions of vigorous star formation G10.6-0.4, W33 in which the morphology of an extended low-level ionized emission component was defined (Ho, Klein, and Haschick 1986). Both of these regions revealed a compact core containing several newly formed OB stars synchronized in their formation to a few $\times 10^4$ years embedded in an extended emission H II region. The extended continuum emission represents ionization by an earlier generation of O stars. Wherever the extended emission encounters dense-cloud condensations, as evidenced from overlaying the NH_3 maps, the ionization appears to surround and flow around them. The morphological relationship of the extended emission component and NH_3 condensations to the compact core suggests that multidimensional shocks are driven into the neutral clumps causing large compressions leading to the formation of new groups of OB stars in the compact core. The morphology of the region and rapid synchronicity of formation lend strong support to the radiation-driven implosion mechanism. Further observations of velocity fields by recombination-line studies (Ho, Klein, Haschick, in preparation) are necessary to confirm the theory for the formation of OB clusters.

3. HIERARCHICAL RADIATION-DRIVEN IMPLOSION

The efficiency of radiation-driven implosion in forming individual OB stars leads us to hypothesize that this mechanism may be responsible for most of the massive star formation in molecular clouds. Consider a *single*, spontaneously formed O star in a clumpy cloud. Inhomogeneities of the proper mass in an annular region around the O star (the "implosion zone") will radiatively implode, forming a new generation of OB stars. Clumps farther away will propagate outward by the rocket effect and those closer in will photo-evaporate. In principle, the new generation of stars can induce further star formation in neighboring clumps, leading to a chain reaction in which the clumps of the proper mass in a group of clumps are converted to stars throughout the molecular cloud in a time of order a few times 10^5 years. The overall efficiency of the star formation may be substantially smaller than 50%, however, because of the ablation experienced by each clump. The length scale over which radiation-driven implosion efficiently makes massive stars is now under investigation. Groups of clumps separated by distances greater than this characteristic length scale could undergo induced star formation by a variant of the Elmegreen-Lada mechanism. Once the first star is formed by this mechanism, inhomogeneities in the unstable layer can be radiatively imploded to form additional stars.

There is an immediate observational consequence of the idea that most massive stars form as the result of radiation-driven implosion: almost all ultra-compact H II regions should be embedded in more extended H II regions with the correct morphological relationship between the ionized and neutral gas. The intensity of the ionizing lux from the inducing star, as inferred from the emission measure of nearly bright rims, for example, must be high enough to drive the implosion.

REFERENCES

Elmegreen, B.G., and C.J. Lada: 1977, Astrophys. J. 214, 723.
Ho, P., Klein, R.I., and Haschick, A.: 1986, to appear in Astrophys. J. Letters.
Klein, R.I., Sandford, M.T., and Whitaker, R.: 1983, Astrophys. J. 271, 269.
Klein, R.I., Whitaker, R., and Sandford, M.T.: 1985, Chapter in *Protostars and Planets II*, Ariz. Press, Ed. D. Black.
Stark, A.A., and Blitz, L.: 1978, Astrophys. J. Letters 225, L15.