QUASISTATIC CONTRACTION OF MAGNETIC PROTOSTARS DUE TO MAGNETIC FLUX LEAKAGE

Takenori Nakano
Department of Physics, Kyoto University

A protostar with sufficient magnetic flux can be in quasistatic equilibrium. The structure at the time t of such an axisymmetric protostar immersed in a medium of finite pressure is determined when the mass m(ϕ, t) in each axisymmetric magnetic tube with the flux ϕ is given. A new distribution m(ϕ, t+δt) is found by calculating the amount of matter which crosses the surface of the magnetic tube ϕ in a time δt due to plasma drift (ambipolar diffusion), and then the structure at t+δt is determined. By repeating this procedure we can follow the quasistatic contraction of a protostar. Here we take into account the effect of charged grains in addition to ions upon the plasma drift.

We have investigated the contraction of a protostar of $50M_\odot$. The protostar is fairly flat initially. The high-density central part contracts faster than the outer part of the disk. The increase of the density accelerates the contraction further. Finally the central part contracts rapidly leaving the outer part nearly unchanged. When the magnetic flux of the central part becomes insufficient to maintain equilibrium, it begins to contract dynamically. Thus, only a part of the protostar becomes a star. For the model investigated several $M_\odot$ contracts finally, which is a few times the Jeans' critical mass at the initial state of the protostar. The friction of grains increases the contraction time by about 30 percent in this model.

DISCUSSION

Bodenheimer: Could you compare the magnetic field strengths that you need for your equilibrium models with observed fields?

Nakano: The upper limits to the magnetic field strengths have been obtained for many molecular clouds, and they are consistent with the strength I have adopted in my model.

Massevitch: In comparing theory and observation, are there not enough observational results or are the observed magnetic fields smaller than required by theory?

D. Sugimoto, D. Q. Lamb, and D. N. Schramm (eds.), Fundamental Problems in the Theory of Stellar Evolution, 63–64.

Nakano: The upper limits to magnetic field strengths that I have mentioned were obtained by attributing the widths of molecular lines to the Zeeman effect, and are fairly large-much larger than required by theory. More direct methods of dtermining B are desirable.

Mouschovias: Please allow me to answer the previous two questions on the status of observations of magnetic fields in dense molecular clouds. The direct Zeeman measurements are performed on the 1720 MHz line of OH; these refer to masers ($\sim 10^{16}$cm), with the result that the "split" in the line may also be due to two masers having some relative velocity. If the OH results are due to the Zeeman effect, they imply that $B \sim$ a few milligauss. This, however, may not represent the mean field in the molecular cloud itself. Observations of the latter field are only indirect (mainly through optical polarization observations). Although their results are consistent with my theoretical prediction $B \propto \rho^{1/2}$, one must await more direct methods of observing B before making definitive statements.

The linewidth argument given by Dr. Nakano is actually a generous overestimate of the upper limit on the magnetic field strength.

Vilhu: I have a very simple and general question in mind. Your computations of magnetic braking in protostars do not have any outflow of matter, like a stellar wind. Is such outflow unimportant?

Nakano: Because I am considering a non-rotating cloud, I do not have a magnetic braking problem. Further, I am investigating the quasistatic contraction of the cloud up to the stage when the central part begins to contract dynamically. Therefore, there is not yet a protostar which could produce a stellar wind.