A BINARY STAR FORMATION MECHANISM THROUGH THE FRAGMENTATION OF PROLATE DENSE CORES ROTATING END OVER END

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Abstract. I propose and briefly elaborate on a major new mechanism for the formation of wide, low-mass binary stars : the fragmentation of a collapsing, initially elongated dense molecular core rotating end over end. This initial structure will develop into two independent gravitationally bound stellar condensations orbiting each other in a rather eccentric orbit.

1. Numerical calculations of binary star formation

The problems of various binary star formation processes have recently been critically reviewed by Pringle (1990, see also Zinnecker 1984). Here I discuss a new process, the fragmentation of slowly tumbling elongated fragments, first mentioned in my review on PMS binaries (Zinnecker 1989). 2D numerical collapse calculations of elongated fragments have been performed by Larson (1972), later by Bastien (1983) and very recently by Rouleau and Bastien (1990); the latter authors also suggest that fragmentation of elongated clouds is an important way of forming binary stars. However, none of these calculations considered or specified the rotational motion of the cylindrical fragments. It is the purpose of this contribution to point out the crucial role of "end over end" rotation in the fragmentation of elongated clouds into binary stars. With rotation of that kind taken into account, the fragmentation problem becomes truly 3D even if magnetic fields are ignored. Such 3D hydrodynamical collapse and fragmentation models of initially prolate, slowly tumbling fragments have never been calculated (except in the context of protostellar fission), yet it may be suspected that it is precisely these initial conditions which could lead to the duplicity of many young low-mass stars.

2. Observations of elongated fragments

The current idea occurred after some new observations of the shapes of dense cores in molecular clouds by Myers et al. (1990) became available. These observations show that most molecular cores, previously studied by Myers and collaborators, actually are not round but are elongated with an aspect ratio of 2 : 1 (perhaps 3 : 1 when deprojected). It is emphasized that elongated structures are seen in the half-power contour maps of at least two optically thin molecular tracers ($C^{18}O$ and CS) and also that these elongated structures cannot be due to rotational flattening of the cores along the rotation axis, because fast rotation (i.e. a substantial

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velocity gradient along the elongation of the cores) is simply not observed, as would be required if the cores were edge-on rotating disks. Therefore it is likely that the cores have a prolate, cigar-shaped structure. Such a geometry is also favored by the fact that many of these elongated cores are found as subcondensations embedded in larger filamentary structures of the parent cloud (Myers, these Proc.; Schneider and Elmegreen 1979). A nice example is TMC-1C (Fiebig and Güsten, priv. commun.) for which the observed position-velocity diagram suggests slow end-over-end rotation. In summary, typical parameters for the observed subcondensations are : length $\sim$ 0.2 pc, diameter $\sim$ 0.1 pc, density $\sim 10^4 - 10^5\,\mathrm{cm}^{-3}$, mass $\sim$ few $M_\odot$, angular velocity $\sim 3{\cdot}10^{-14}\,\mathrm{sec}^{-1}$, specific angular momentum = rot. vel. $\times$ length/6 $\sim 10^{21}\mathrm{cm}^2\,\mathrm{sec}^{-1}$.

3. Evolution of protobinary systems

Fig. 1 sketches prolate subcondensations in a filamentary cloud and the subsequent evolution of a subcondensation into a binary system. Even without detailed 3D calculations (still to be performed), some essential features of the evolution of a rotating, gravitationally unstable prolate clump may be anticipated : first the moderately prolate clump will collapse to a more prolate, thin bar which will subsequently break up into two (or perhaps in some cases three) fragments. Because of the non-axisymmetric bar-like configuration, specific angular momentum will be transported outward and the material trailing beyond the dumbbell-shaped, protobinary structure will exert some gravitational torque on the protobinary components, slowing down their orbital motion and shrinking their orbit.

Initially the components of the protobinary system will be on nearly radial orbits, since the components will fall towards each other due to their mutual gravitational attraction while centrifugal forces will initially be dynamically negligible at large separations (10000 AU). However, the initial angular momentum will prevent the components from merging into a single object, i.e. at smaller separations of the components (1000 AU) the centrifugal forces will grow. Meanwhile circumstellar disks of small extent (10-100 AU) may have formed around each component. When the components are getting closer, their disks are likely to interact either directly or tidally, and rapid outer disk disruption and inner disk accretion onto the star may be induced. Drag forces will make the orbit somewhat more circular but a certain non-zero eccentricity will survive after dissipation ceases. The end result is a gravitationally bound pair of T Tauri stars with component separation of order 100 - 1000 AU, with a rather eccentric orbit, and with little circumstellar disk material but possibly with remnant circumbinary debris of gas and dust (i.e. a pair of "naked" T Tauri stars, cf. Walter et al. 1988).

Observations indeed support one of the key predictions of this model : according to Duquennoy and Mayor (1989) the wide binaries in a complete sample of 210 F and G stars exhibit an eccentricity distribution of $f(e) = 2e$, i.e. most systems have substantial eccentricities, as predicted in the present scenario. Furthermore, an example of a protobinary object formed from an elongated cloud might be IRAS 16293-2422 with an observed projected component separation of about 800 AU (Wootten 1989).

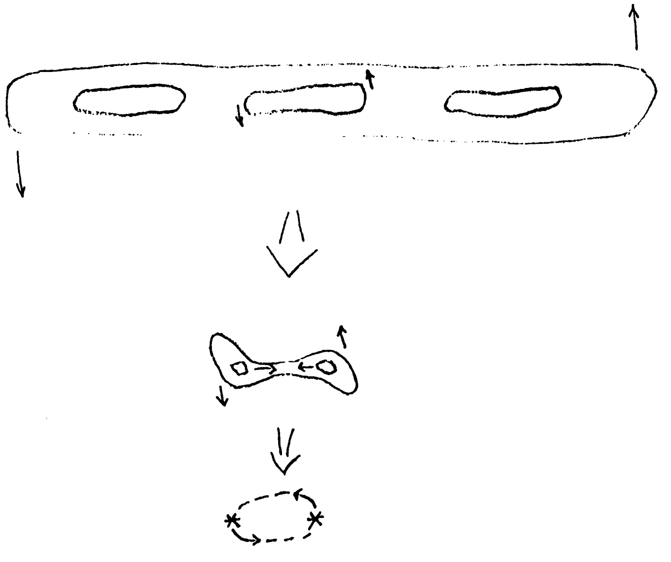

Fig. 1. Schematic evolution of a prolate subcondensation in a filament into a protobinary system. Here the angular momentum vector is perpendicular to the plane of the sky. The velocity gradient along the filament is $\sim 1\,\mathrm{km\,s^{-1}\,pc^{-1}}$. Arrows indicate the direction of motion. The initial length of the subcondensations is $\sim 0.2\,\mathrm{pc}$, the final major axis of the binary system is between 100 and 1000 AU.

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