# Protobinary Evolution Driven by Magnetic Braking

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## Introduction

The majority of stars (~75%) reside in binary and multiple systems. The fraction is even higher for young stellar objects, indicating that the formation of multiple system, especially binaries, is a major mode of star formation.

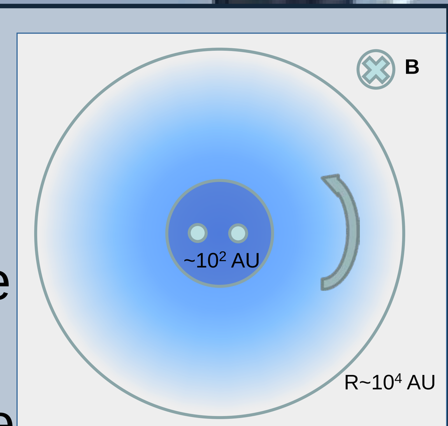
Recent observations of protostellar objects showed a "desert" free of Class 0 binaries with separation between ~150-550AU, which is not present in the Class I or later phases. The inconsistency indicates that binaries may migrate substantially from their birth location.

We focus on one possible mechanism for binary migration: magnetic braking. It is a key factor to understand binary formation and evolution in dense cores that are observed to be strongly magnetized.

Our study addresses the following questions:

- How different magnetic field strengths affect the evolution of binary properties, especially the binary separation and mass ratio?
- How does the misalignment between the magnetic field and rotation axis change the properties?

## Methods




We use the ENZO code with sink particles. The cloud core is modeled as a singular isothermal sphere with profile $\rho(r)\sim 1/r^2$, $v_\varphi(\theta)\sim v_0\sin\theta$, $B_z(r)\sim 1/r$. We assume the binary seeds have already formed at the beginning of the calculation.

## Result 1: Equal-Mass Binary

Fig. 1 compares two extreme cases: the non-magnetic case and the strongest field case (mass-to-flux ratio λ=2). Both **circumstellar** disks and **circumbinary** disk are prominent in the former case, while absent in the latter. The binary **separation** is also much smaller in the presence of strong magnetic field.

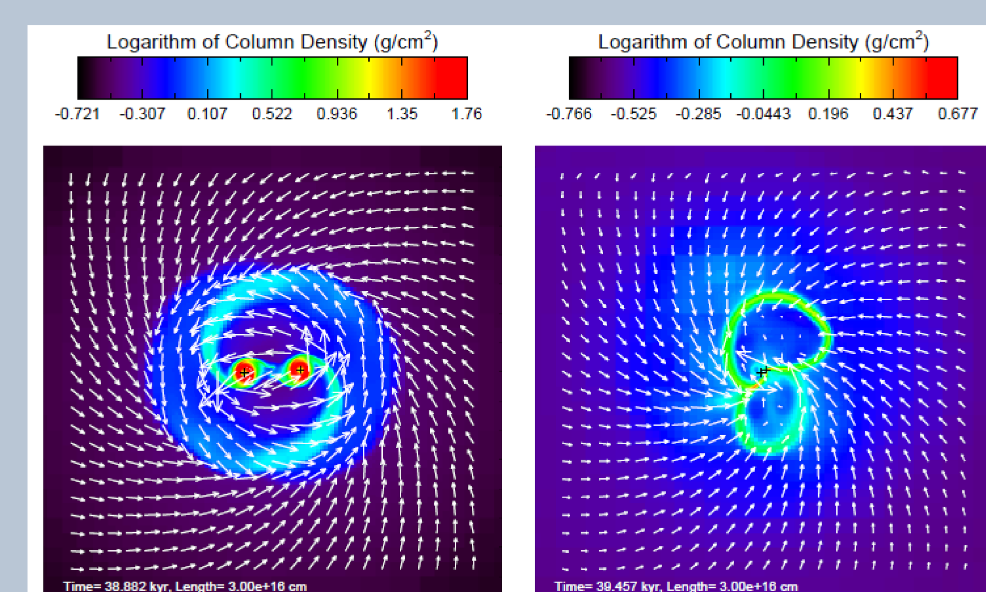



*Fig. 1 Distribution of the logarithm of the column density along z-direction and velocity field on the equatorial plane. Both the non-magnetic (left) and λ=2 (right) case are at t~39kyr. The well-defined disk structures are replaced by magnetically dominated lobes in the latter. The binaries are marked by crosses.*

The evolution of binary separation in Fig. 2 (left) indicates that: the stronger the core is magnetized, the tighter the separation.

The self-similarity of the core predicts a linear relation between the binary orbital angular momentum $L_b$ and the total mass $M_b$. The non-magnetized case matches with the analytical scaling, whereas the loss of orbital angular momentum becomes more severe in stronger field cases.

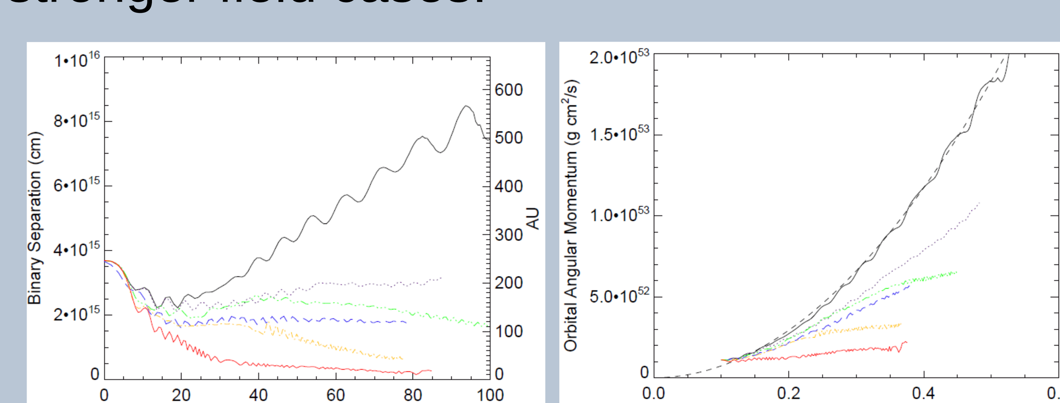
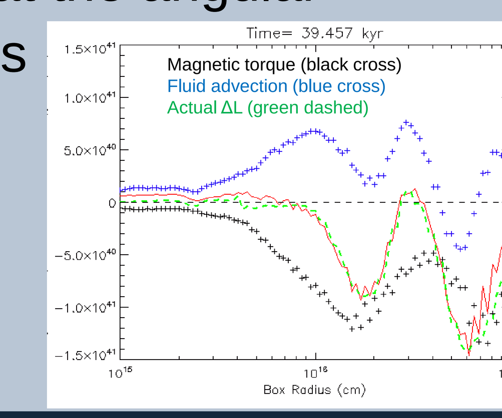



*Fig. 2 (Left) Evolution of binary separation with time. (Right) The relation between angular momentum and total mass of the binary. The different curves are: non-magnetic (black), λ=32 (purple), λ=16 (blue), λ=8 (green), λ=4 (yellow), and λ=2 (red) cases.*

## Migration from Magnetic Braking

The magnetic field does not act on the stars directly. However, through magnetic braking, it can remove the angular momentum of the infalling material prior to the arrival at the binary seeds. We find that the angular momentum advected in is mainly removed by the magnetic torque rather than gravitational toque.




## Result 2: Unequal-Mass Binary

The observed distribution of binary mass ratio is roughly flat, yet hydrodynamical simulations tend to over-produce equal-mass binaries by preferential accretion onto the low-mass binary companion. In our study, magnetic braking can suppress the mass ratio growth by removing the angular momentum of the accreting gas.

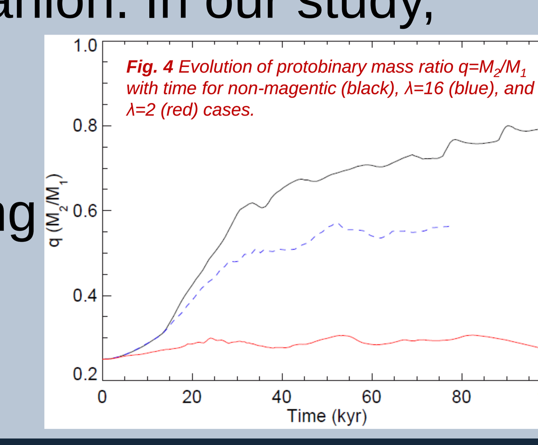



*Fig. 4 Evolution of protobinary mass ratio $q=M_2/M_1$ with time for non-magentic (black), λ=16 (blue), and λ=2 (red) cases.*

## Result 3: Effect of Magnetic Field Misalignment

Numerical calculations have shown that the misalignment between the magnetic field and rotation axis may weaken the magnetic braking and outflows. We find that, for binaries, misalignment tightens the binary orbit, due to faster mass accretion yet slower increase in angular momentum.

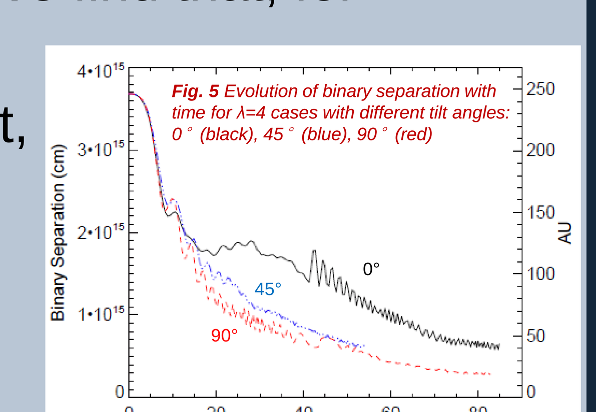



*Fig. 5 Evolution of binary separation with time for λ=4 cases with different tilt angles: 0° (black), 45° (blue), 90° (red)*

## Weaker Outflow Boosts $\dot{M}$

Larger field misalignment has weaker gas outflow that allows more infalling gas to be accreted onto the binary stars. The faster accretion of low specific angular momentum gas leads to the tighter binary separation.

The misalignment also affects the disk morphology. Keplerian circumbinary disks may survive.

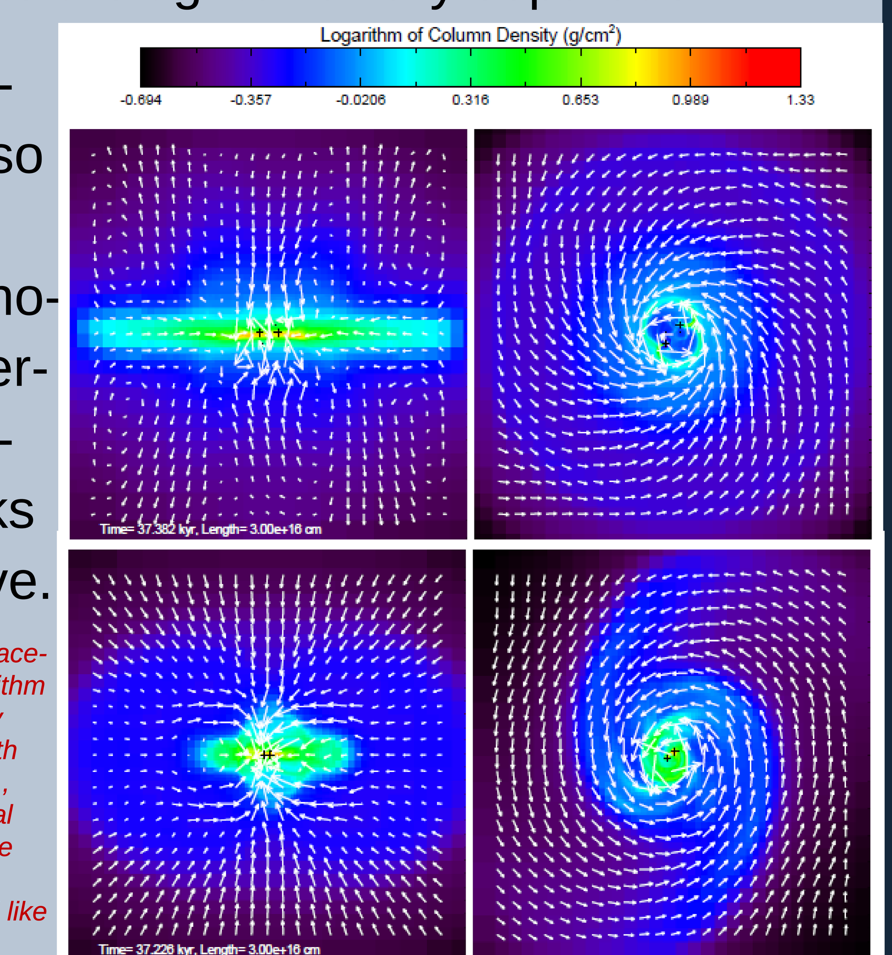



*Fig. 6 Edge-on and face-on views of the logarithm of the column density and velocity field. Both the aligned case (0°, upper) and orthogonal case (90°, lower) are for λ=4. The pseudo-spirals are snail-shell like magnetic structures.*

## Conclusion

We found that a magnetic filed of the observed strength can remove, through magnetic braking, most of the angular momentum of the material that reaches the protobinary. Compared with the non-magnetic case: **(1)** the protobinary orbit becomes much tighter, i.e. inward migration, **(2)** the mass-ratio does not increase as fast with time for initially unequal mass binaries, **(3)** field misalignment tightens the binary orbit further.

## *Reference*

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We thank P. Arras, S. Offner, K. Kratter, C.Matzner, and A.Maury for useful discussion and P. Wang for advice on the ENZO code.