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Binary-First Star Formation as a Persistence-Selected Outcome of Open, Embedded Protostellar Dynamics

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ABSTRACT

Multiplicity is highest at the youngest observable protostellar stages and declines toward field values, suggesting that what surveys measure is not merely a formation rate but a survival-filtered population. This paper proposes a conservative theoretical framework for early star formation in dense, embedded environments, modeled as open systems with sustained mass and angular-momentum fluxes across their boundaries. The central organizing principle is a persistence bias: the observable abundance of a multiplicity configuration class C is approximately lifetime-weighted, $\Pi_C \propto \lambda_C \tau_C$, where λ_C denotes the effective entry rate into class C and τ_C its mean persistence time under perturbations, dissipation, and continuing inflow. In such environments, fragmentation can generate numerous transient centers, but non-hierarchical higher-order systems decay rapidly, while compact pairs are preferentially hardened by dissipation, encounters, and accretion. As a result, binaries are statistically favored among luminous survivors. The framework is explicitly conditional, targeting dense Class 0/I regions and treating lower-density environments as limiting cases. Connections to embedded multiplicity surveys and implications for future observations and simulations are discussed.

Keywords: star formation — binaries: general — ISM: clouds — accretion, accretion disks — magnetohydrodynamics — turbulence

1. INTRODUCTION

Binary and multiple stellar systems are ubiquitous across stellar masses and environments, yet multiplicity is not static over time. Observations consistently show that the youngest embedded populations exhibit higher multiplicity fractions than older pre–main-sequence stars and field populations (Duchêne & Kraus 2013; Offner et al. 2022; Tobin et al. 2022; Moe & Di Stefano 2017). This systematic decline with age motivates a reversal of the standard question. Rather than asking why binaries form, one may ask why isolated single-star outcomes should dominate at all in dense, gas-rich, dynamically active birth environments.

In embedded regions, this age dependence is commonly attributed to dynamical evolution, migration, and disruption acting on initially richer multiple populations. The present work offers a compact theoretical synthesis of this view by emphasizing persistence rather than formation. What surveys observe is not a snapshot of instantaneous fragmentation, but the subset of configurations that survive repeated perturbations during the embedded phase.

The framework developed here does not introduce new microphysics. Instead, it reorganizes the interpretation of well-established processes—gravity, accretion, angular momentum transport, radiative feedback, and magnetic fields—by identifying persistence under non-equilibrium conditions as the dominant selection mechanism shaping observed multiplicity.

1.1. *Observational selection as a separate layer*

Multiplicity statistics are further shaped by distance-dependent detectability. Visual binaries require angular separations above instrumental resolution, while flux-limited samples bias against faint companions. Spectroscopic detections depend on signal-to-noise ratios that degrade with distance and extinction. Large photometric surveys demonstrate that unresolved binaries can be abundant while remaining inaccessible to direct imaging (Kirk et al. 2016). These observational effects are distinct from the physical persistence bias emphasized below, though both can act in the same direction. Meaningful comparisons therefore require completeness-aware analyses (Duchêne & Kraus 2013; Moe & Di Stefano 2017; Offner et al. 2022).

2. DEFINITIONS AND SCOPE

A configuration class C denotes a coarse-grained multiplicity category (single, binary, hierarchical triple, non-hierarchical triple) within a specified separation and mass range. An open embedded volume is a gas-rich star-forming region in which protostellar objects exchange mass and angular momentum with their surroundings through inflow, outflow, and interactions, rather than evolving as isolated closed systems. The persistence time τ_C is the mean duration for which a system remains in class C before transitioning through hardening, disruption, merger, or ejection.

The framework is intended for dense Class 0/I environments where interaction rates are non-negligible and external supply persists. Lower-density regions and very low-mass regimes are treated as limiting cases.

3. LIFETIME-WEIGHTED MULTIPLICITY

The central organizing principle is that the observable abundance of configuration class C is approximately lifetime-weighted,

$$\Pi_C \propto \lambda_C \tau_C, \tag{1}$$

where λ_C is the effective rate at which systems enter class C, and τ_C is the mean persistence time under local conditions.

This relation is not a closed predictive model but a structural identity elevated to an interpretive principle. It clarifies how high formation rates can yield low observed frequencies if persistence times are short, and how modest entry rates can dominate if persistence is long. This distinction is crucial in gas-rich embedded phases where dissipation, accretion torques, and encounters rapidly reshape multiplicity (Bate 2012; Offner et al. 2022; Kuruwita & Haugbølle 2023).

3.1. *On the scope of the framework*

This work is intentionally framed as a theoretical synthesis rather than a quantitative closure. Persistence times τ_C are not universal constants; they depend on environmental density, accretion geometry, magnetic topology, and the history of asymmetric inflow and feedback. Without specifying these boundary conditions explicitly, numerical estimates would be arbitrary. The purpose of the present framework is therefore to identify which quantities should be measured or simulated, not to assign values prematurely.

4. PHYSICAL INGREDIENTS

Fragmentation naturally occurs in turbulent, rotating collapse, producing multiple condensations rather than a single symmetric object (Larson 1985; Tohline 2002; Bate 2012). In crowded embedded volumes, few-body interactions are frequent and dynamically consequential.

Angular momentum redistribution via disks, tides, and resonances provides additional channels for dissipation in binaries and higher multiples (Artymowicz & Lubow 1994, 1996; Kratter & Lodato 2016). Radiative feedback regulates fragmentation but does not enforce isolation, particularly when accretion is anisotropic (Offner et al. 2014).

Magnetic fields alter collapse and angular momentum transport while introducing additional dissipation pathways in multi-center geometries (Crutcher 2012; Hennebelle & Inutsuka 2019; Seifried et al. 2015). Continued external supply through filaments and cloud-scale flows sustains interactions and delays isolation (Hacar et al. 2023).

5. PERSISTENCE OF PAIRS

Non-hierarchical few-body systems are generically unstable, whereas compact binaries act as energy sinks that can be hardened by encounters and dissipation (Heggie 1975; Hut & Bahcall 1983). In gas-rich environments, disk torques and accretion-driven evolution further favor compactification (Kuruwita & Haugbølle 2023). Hierarchical higher-order systems can persist in extreme environments, but their residence times depend strongly on density and mass scale (Li et al. 2024).

6. TEMPORAL STAGING

Multiplicity evolution may be viewed in three stages: initial fragmentation, obscured dynamical selection during deeply embedded phases, and observable survivors. Surveys primarily sample the final stage, after significant filtering has already occurred (Duchêne & Kraus 2013; Offner et al. 2022; Tobin et al. 2022).

7. REPEATED ASYMMETRIC DEUTERIUM-TRIGGERED EVENTS

Early protostars lack a formed core, hydrostatic equilibrium, and symmetric accretion. Deuterium burning therefore initiates locally through multiple false starts when transient regions reach threshold conditions (Stahler 1988; Palla & Stahler 1999; Baraffe et al. 2009; Audard et al. 2014; Dunham et al. 2014). These events are intrinsically asymmetric and impulsive.

For isolated protostars, repeated asymmetric events eject mass and momentum irreversibly, disrupt accretion geometry, and can terminate stellar growth entirely. In binary systems, ejected material remains gravitationally accessible to the companion, enabling mass exchange rather than loss. Impulse-driven perturbations preferentially disrupt disk structures rather than the binary orbit, enhancing non-stationary accretion and recycling (Artymowicz & Lubow 1996; Kratter & Lodato 2016; Vorobyov et al. 2018). Repeated events therefore shorten τ_{single} while extending τ_{pair}.

8. OBSERVATIONAL IMPLICATIONS

Embedded surveys such as VANDAM sample persistence-selected survivors rather than initial fragmentation products (Tobin et al. 2022). The observed decline of multiplicity with age is naturally interpreted as continued filtering. Singles emerging from dense regions are expected to show broader kinematic dispersions and signatures of ejection (Bate 2012). Disk morphologies in binaries should preferentially show circumbinary reservoirs and streamers (Dutrey et al. 2014).

9. LIMITATIONS AND FUTURE WORK

Quantitative tests require residence-time measurements from long-duration, open-boundary radiation-MHD simulations and completeness-corrected observational analyses. The present framework identifies the relevant variables and selection mechanisms but does not prescribe their numerical values.

10. CONCLUSIONS

Early star formation in dense embedded environments is proposed to be persistence-selected rather than formation-limited. Fragmentation produces many transient configurations, but dissipation, accretion, and repeated asymmetric non-equilibrium events favor the survival of compact pairs. Binaries are therefore statistically favored among luminous survivors, while many observed singles may represent late-stage outcomes of persistence failure.

REFERENCES

Artymowicz, P., & Lubow, S. 1994, ApJ, 421, 651

Artymowicz, P., & Lubow, S. 1996, ApJL, 467, L77

Audard, M., et al. 2014, Protostars and Planets VI, 387

Baraffe, I., et al. 2009, ApJL, 702, L27

Bate, M. 2012, MNRAS, 419, 3115

Crutcher, R. 2012, ARAA, 50, 29

Duchêne, G., & Kraus, A. 2013, ARAA, 51, 269

Dunham, M., et al. 2014, Protostars and Planets VI, 195

Dutrey, A., et al. 2014, Nature, 514, 600

Hacar, A., et al. 2023, Protostars and Planets VII

Heggie, D. 1975, MNRAS, 173, 729

Hennebelle, P., & Inutsuka, S. 2019, Front. Astron. Space Sci., 6, 5

Hut, P., & Bahcall, J. 1983, ApJ, 268, 319

Kirk, B., et al. 2016, AJ, 151, 68

Kratter, K., & Lodato, G. 2016, ARAA, 54, 271

Kuruwita, R., & Haugbølle, T. 2023, A&A

Larson, R. 1985, MNRAS, 194, 809

Li, S., et al. 2024, Nat. Astron., 8, 472

Moe, M., & Di Stefano, R. 2017, ApJS, 230, 15

Offner, S., et al. 2014, Protostars and Planets VI, 53

Offner, S., et al. 2022, ApJ, 925, 39

Palla, F., & Stahler, S. 1999, ApJ, 525, 772

Seifried, D., et al. 2015, MNRAS, 446, 2776

Stahler, S. 1988, ApJ, 332, 804

Tobin, J., et al. 2022, ApJ, 925, 39

Tohline, J. 2002, ARAA, 40, 349

Vorobyov, E., et al. 2018, A&A, 614, A98