Observational Tests of Multiple Star Formation Scenarios: Case Studies of VLA 1623-2417 and L1551 IRS 5

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Abstract. This paper examines whether observations of young multiple stellar systems are consistent with theoretical predictions regarding the prevalence of multiplicity in star-forming environments. We analyze VLA 1623-2417, a hierarchical multiple system in Rho Ophiuchi, and L1551 IRS 5, a close binary in Taurus. Recent ALMA, VLA, and JWST data reveal complex circummultiple disk structures, accretion streamers, and distributed outflow activity. However, these features are also predicted by standard turbulent fragmentation models. We find that while multiplicity is clearly common, current data cannot establish whether it is preferentially "optimal" versus simply a natural outcome of turbulent cloud fragmentation.

Keywords: star formation — multiple systems — protostars — binaries — accretion

1. Introduction

Stellar multiplicity surveys show that binary and higher-order systems dominate among young populations: 60–75% for Class 0/I protostars [Tobin et al., 2022], declining to 40–50% in field populations [Duchêne and Kraus, 2013, Moe and Di Stefano, 2017].

Two explanations exist: (1) **Turbulent fragmentation** [Bate, 2012, Offner et al., 2022], where multiplicity arises naturally from cloud fragmentation; (2) **Systematic advantages** [Kriger, 2026], where multiple configurations provide physical benefits. This paper examines whether observations can distinguish these scenarios.

We emphasize distinguishing *consistency* (observations don't contradict predictions) from *validation* (observations uniquely confirm predictions).

2. VLA 1623-2417: Hierarchical Multiple System

VLA 1623-2417 in Rho Ophiuchi ($\sim$140 pc) contains at least four components [Murillo et al., 2018, Mercimek et al., 2023, Radley et al., 2025]: A1+A2 ($\sim$30–50 AU inner binary), B ($\sim$150 AU), and W ($\sim$1200 AU).

ALMA observations reveal: spiral structures and gaps; unsettled mm dust around B; accretion streamers (FAUST program); varying dust grain growth. These are consistent with material redistribution but also arise from standard binary-disk interactions [Dong et al., 2015].

Multiple outflows with different position angles confirm distributed feedback, though this is trivially expected when multiple protostars are present.

Implications: Binary-specific calculations don't apply to this four-body hierarchy. Kozai-Lidov oscillations may dominate over idealized mass exchange.

3. L1551 IRS 5: Close Binary

L1551 IRS 5 in Taurus ($\sim$147 pc) has separation $\sim$47–53 AU [Rodríguez et al., 2003], a possible third component at $\sim$13 AU [Lim and Takakuwa, 2006], circumbinary structure with cleared cavity, and dual misaligned jets [Takakuwa et al., 2020].

Misaligned circumstellar disks could indicate AM redistribution but also arise from turbulent fragmentation [Offner et al., 2016, Bate, 2012]. Asynchronous jet activity is inconclusive—stochastic variation is equally plausible.

4. Critical Evaluation of Mechanisms

Mass Redistribution: The original "deuterium burst ejection" claim requires correction. D-burning is a steady thermostat [Palla and Stahler, 1993, Chabrier et al., 2000], not episodic. Outbursts (FU Ori) are accretion-driven [Audard et al., 2014, Hartmann et al., 2016]. Circumbinary disks do serve as mass reservoirs, but this is a standard prediction.

Angular Momentum: Orbital AM reservoirs are physically plausible [Artymowicz and Lubow, 1994, Bate et al., 2000], but claimed timescale advantages need simulation verification.

Orbital Stability: The physics is sound [Hills, 1983], but practical advantage depends on perturbation magnitudes.

Enhanced Capture: Geometrically correct [Moeckel and Bally, 2010], but requires validation across realistic cloud conditions.

Distributed Feedback: Trivially expected; requires radiation-MHD simulations [Krumholz et al., 2009, Offner et al., 2009] for stability comparison.

Mutual Equilibration: Elegant mathematically, but observational evidence is weak.

5. Turbulent Fragmentation Alternative

Multiplicity is well-explained by turbulent fragmentation: core fragmentation from supersonic turbulence [Offner et al., 2022, Padoan and Nordlund, 2002]; disk fragmentation [Kratter and Lodato, 2016, Stamatellos and Whitworth, 2009]; declining multiplicity with age from dynamical processing [Reipurth et al., 2014, Parker and Goodwin, 2014].

6. Conclusions

(1) Multiplicity is common, not necessarily optimal. (2) Observations are consistent with but don't uniquely validate proposed mechanisms. (3) Hierarchical multiplicity complicates binary-focused frameworks. (4) The "deuterium burst" mechanism is not supported. (5) Direct validation requires numerical simulations and statistical comparisons.

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