The Origin and Evolution of Jupiter-Mass Binary Objects

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Context + Method

- Discovery of 42 Jupiter-mass binary objects (JuMBOs) in the Trapezium cluster from a population of 540 (~8%) free-floating Jupiter-mass objects (JMO) [1]. Observations of this rich population deserves an understanding of their origins.
- These are extremely soft systems, ionising upon any encounter. Typical star (m_* = 0.35 $M_\odot$) in the Trapezium cluster and free-floating JMOs have more kinetic energy than the typical JuMBO ($m_1 = m_2$ = 1 M_{Jup}, semi-major axis a = 100 au) binding energy.

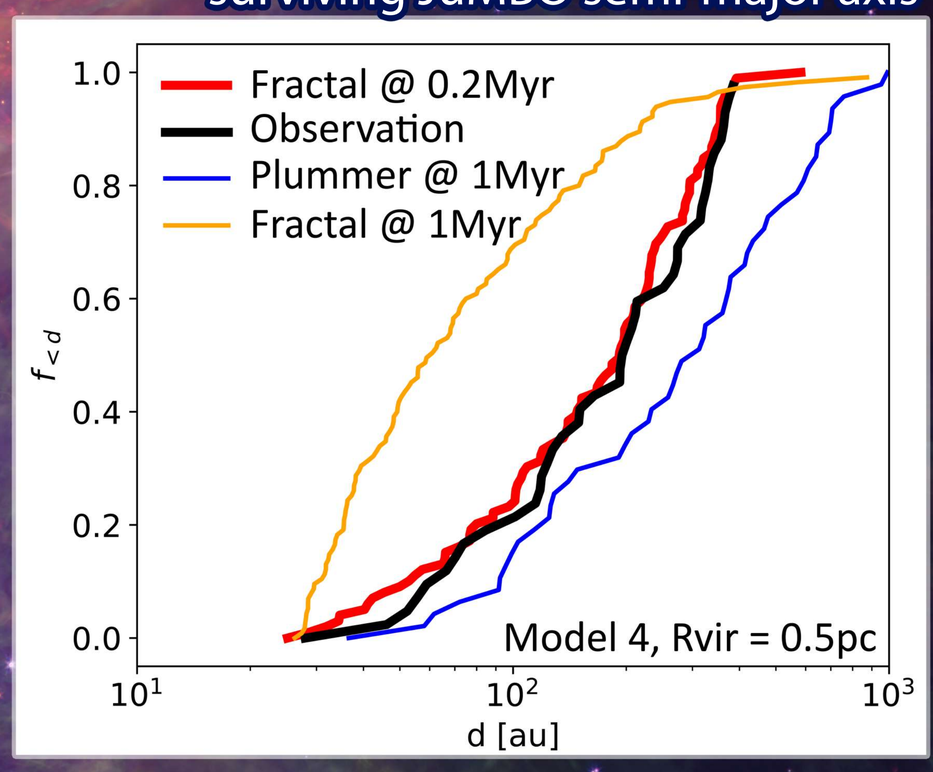
- Direct N-body integration until t_{end} = 1 Myr.
- JMO masses: $m_{JMO} \in$ [0.8, 14] M_{Jup} with power-law α = -1.2.
- Cluster populations: N_* = 2500, N_{JMO} = 600.
- Spatial distribution: Plummer or Fractal distribution.
- Virial radius of 0.25, 0.50 or 1.00 pc.
- Neglect stellar evolution + galactic tidal field.

Table 1: JuMBO Survival rate after 1 Myr

R_{vir} [pc]	0.25		0.50		1.00	
Model	Plummer	Fractal	Plummer	Fractal	Plummer	Fractal
Model 1: FFC	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Model 2: SPP	0.20%	0.03%	0.20%	0.06%	0.20%	0.03%
Model 3: SPM	6.00%	1.67%	14.7%	5.67%	5.00%	8.67%
Model 4: ISF	7.67%	0.00%	37.0%	2.00%	72.0%	4.00%

* Values denote (# of JuMBOs)/(Total # of JMOs)

Figure 1: Cumulative distribution of surviving JuMBO semi-major axis



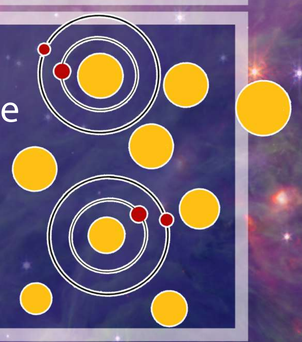
Dynamical Origin?

Model 1 (Free-Floating Capture):
- Formation of JuMBO by free-floating JMO capturing one another.
- No JuMBOs form let alone survive after 1 Myr.
- Simulations which increased N_{JMO} = 10^4 also form zero JuMBOs.

Verdict: Not the formation pathway

Model 2 (Star-Planet-Planet):
- Stars host two wide-orbit JMO. Upon dynamical encounter, the JMOs are ejected from their host, forming a soft binary.
- Roughly 0.1 JuMBO survive after 1Myr.
- One JuMBO for every 5 000 ~ 10 000 free-floating JMO

Verdict: Not the formation pathway



Model 3 (Star-Planet-Moon):
- Stars host a JMO who is orbitted by another JMO. Dynamical encounter will strip the two JMO's from the host, and they form a soft binary.
- Between ~5 - 40 JuMBO survived after 1Myr.
- One JuMBO for every 20 ~ 100 free-floating JMO.

Verdict: Possible path JuMBOs but requires fine-tuned conditions.
Namely a significant number of stars host two JMOs at 900 AU <.

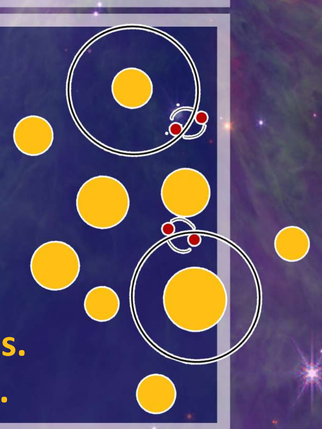
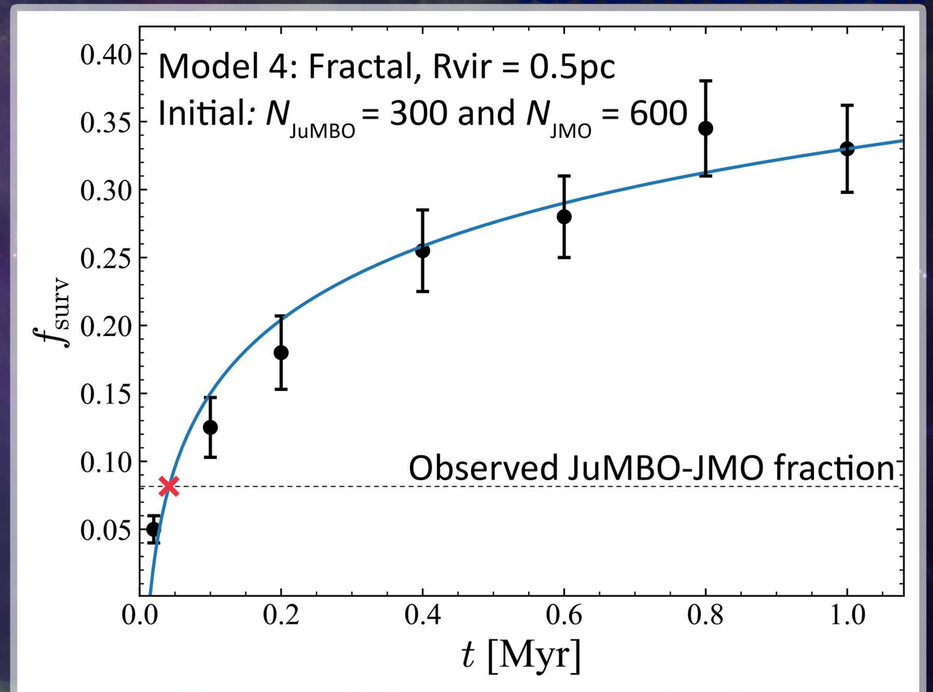


Figure 2: Time of JuMBO introduction vs. survival fraction



In-Situ Formation?

Model 4 (In-situ Formation):
- JuMBOs form in-situ via familiar star formation processes.
- Fractal clusters being violent efficiently ionise JuMBOs, leaving only the tightest binaries.
- Plummer sphere being a relaxed system have little JuMBO evolution. Final parameters reflect initial conditions.
- Fractal configuration with R_{vir} = 0.5pc form ~4 triples for every 40 JuMBO. Plummer models do not form triples.
- Inserting JuMBOs after the initial violent phase can recover the observed semi-major axis distribution (figure 1) and increases the survival fraction (figure 2).
- To match the observation rates for a Trapezium-like cluster [2], JuMBOs must have formed roughly 50 kyr to 200 kyr after the stars.

Verdict: Most likely path.

References

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[1] Pearson, S.G., McCaughrean, M.J.: Jupiter Mass Binary Objects in the Trapezium Cluster. arXiv e-prints, 2310–01231 (2023) https://doi.org/10.48550/arXiv.2310.01231 arXiv:2310.01231 [astro-ph.EP]

[2] Portegies Zwart, S.F.: Stellar disc destruction by dynamical interactions in the Orion Trapezium star cluster. 457(1), 313–319 (2016) https://doi.org/10.1093/mnras/stv2831 arXiv:1511.08900 [astro-ph.SR]

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