

Stolen Planets in Star-Forming Regions

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Importance

Exoplanets

Some exoplanets have been observed on **extremely wide orbits, beyond 1000 AU** [1,2]. This is too far away from their star for them to have formed where they have been observed. So, they must have been **moved there by some mechanism** [2]. These include, ejection due to a passing star, instabilities within a multi-planet system, the capture of free-floating planets, and **theft from another star**.

The Solar System

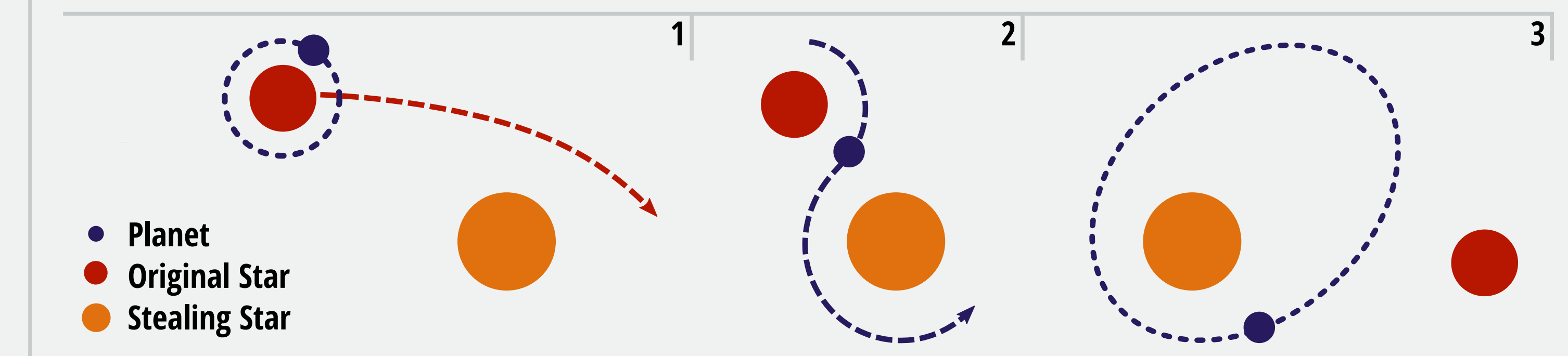
There may also be a **stolen planet in the Solar System** [2,3]. **Planet 9** is a **hypothetical planet**, proposed to explain the observed clustering of some Kuiper Belt objects [3]. It is thought to have a **wide** (semimajor axis ~380-980 AU, perihelion ~150-350 AU), **eccentric** (~0.6), and **inclined** (~30°) orbit [4].

Star Formation

The **majority of stars**, and therefore planets, appear to form in **relatively dense star-forming regions** [5,6]. And, there is evidence that the Sun may also have formed in such an environment [7]. These regions can reach **peak densities of >1000 M_⊙ pc⁻³**, making dynamical interactions including **theft more likely** [8].

What is Planet Theft?

When a planet is **directly exchanged between stars** during an encounter. These planets are **not free-floating** in between orbits, and are therefore expected to have different orbital characteristics to captured free-floating planets.



Method

Direct N-body simulations of young star-forming regions, evolved for 10 Myr. Multiple realisations summed for each set of initial conditions.

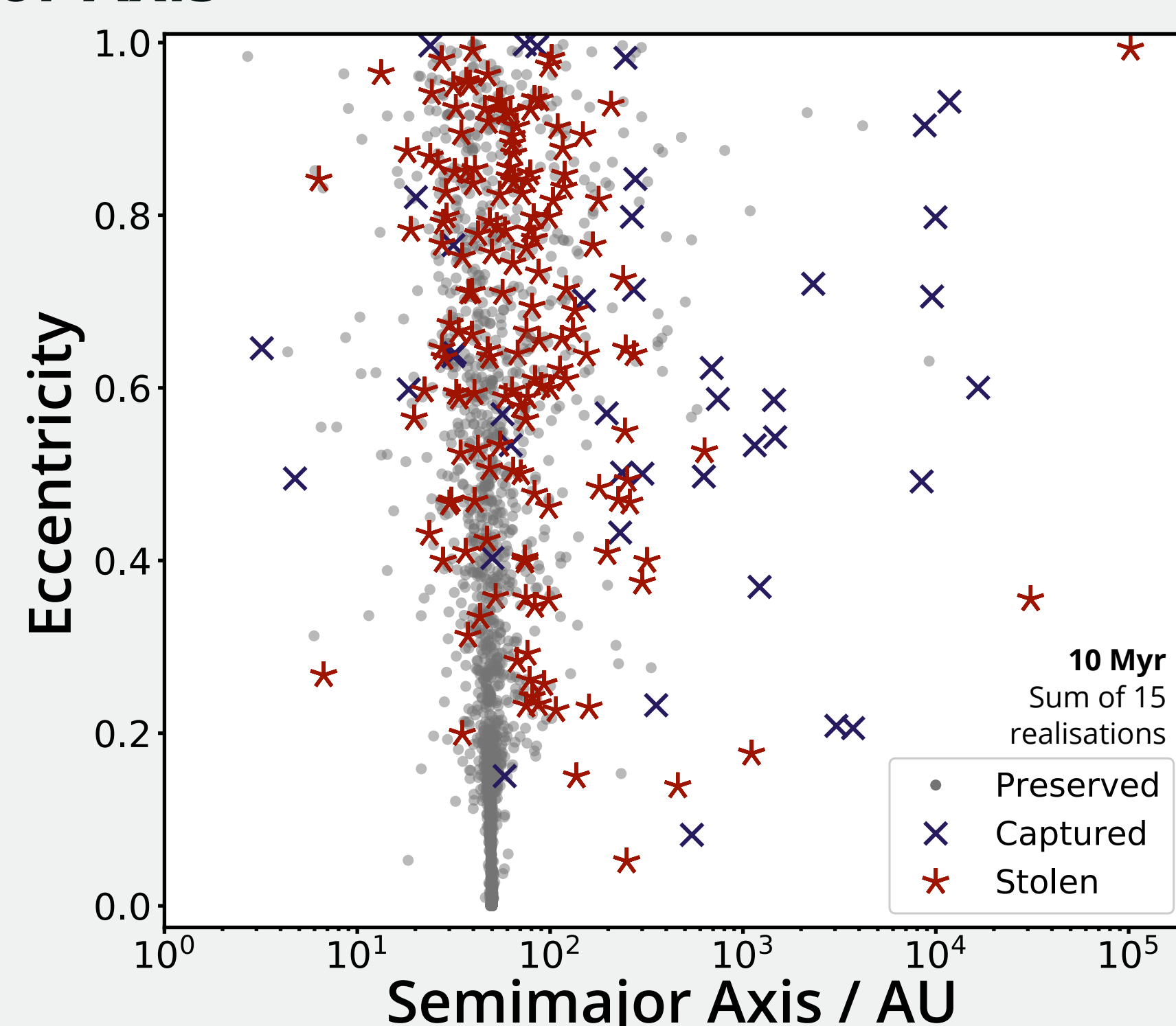
Initial Conditions Used Here

- 1000 stars
- Maschberger IMF
- Virial Ratio = 0.3 (initially collapses)
- Fractal Dimension = 1.6 (very clumpy)
- 50% of stars have planets
- Jupiter Mass
- Semimajor Axis = 50 AU
- Eccentricity = 0

Results

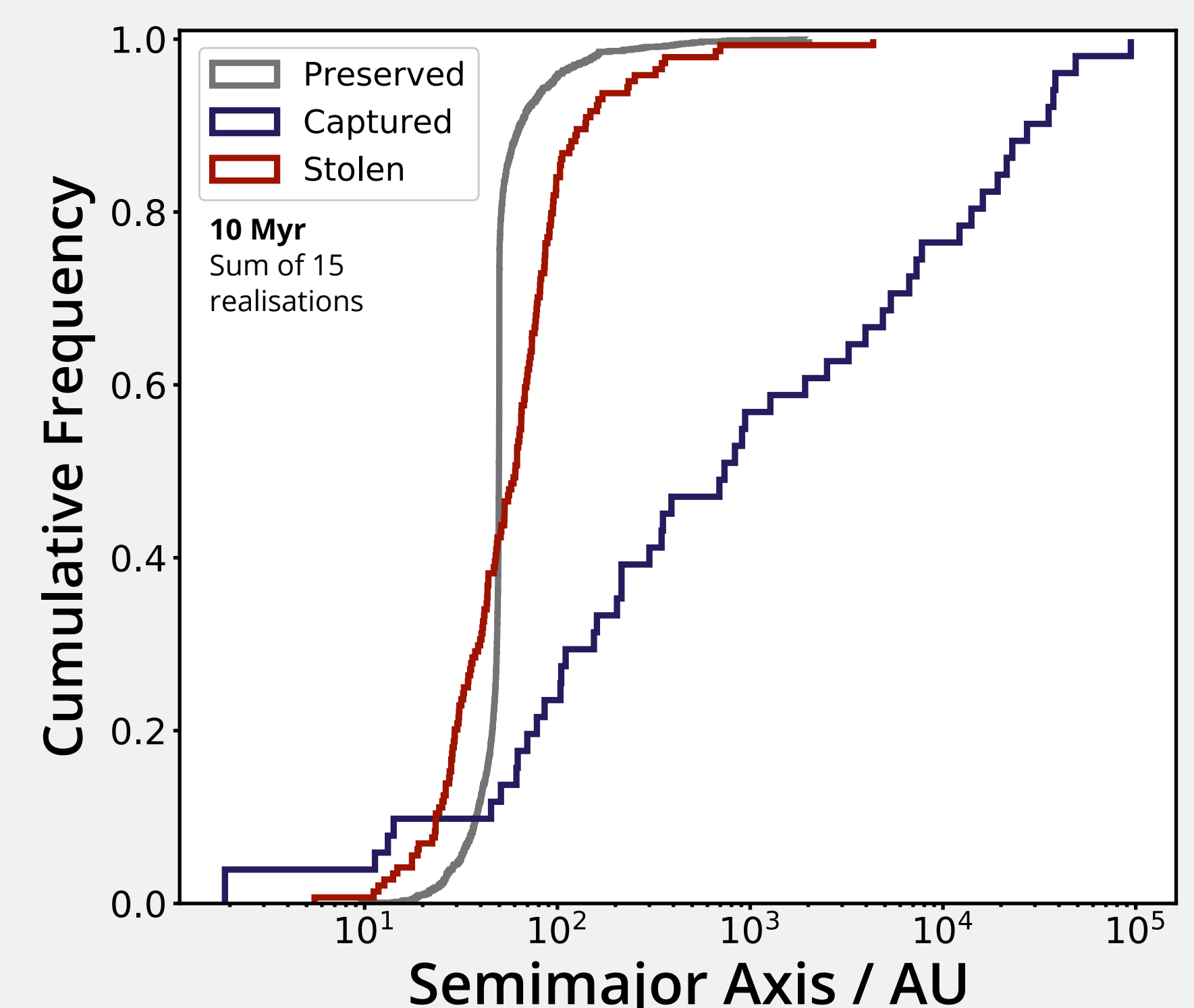
Eccentricity vs Semimajor Axis

- Significant amount of planet theft - more stolen than captured planets for these initial conditions.
- Theft can produce orbits similar to Planet 9 in semimajor axis and eccentricity.
- A significant amount of stolen and captured planets occupy the same parameter space as disrupted preserved planets.



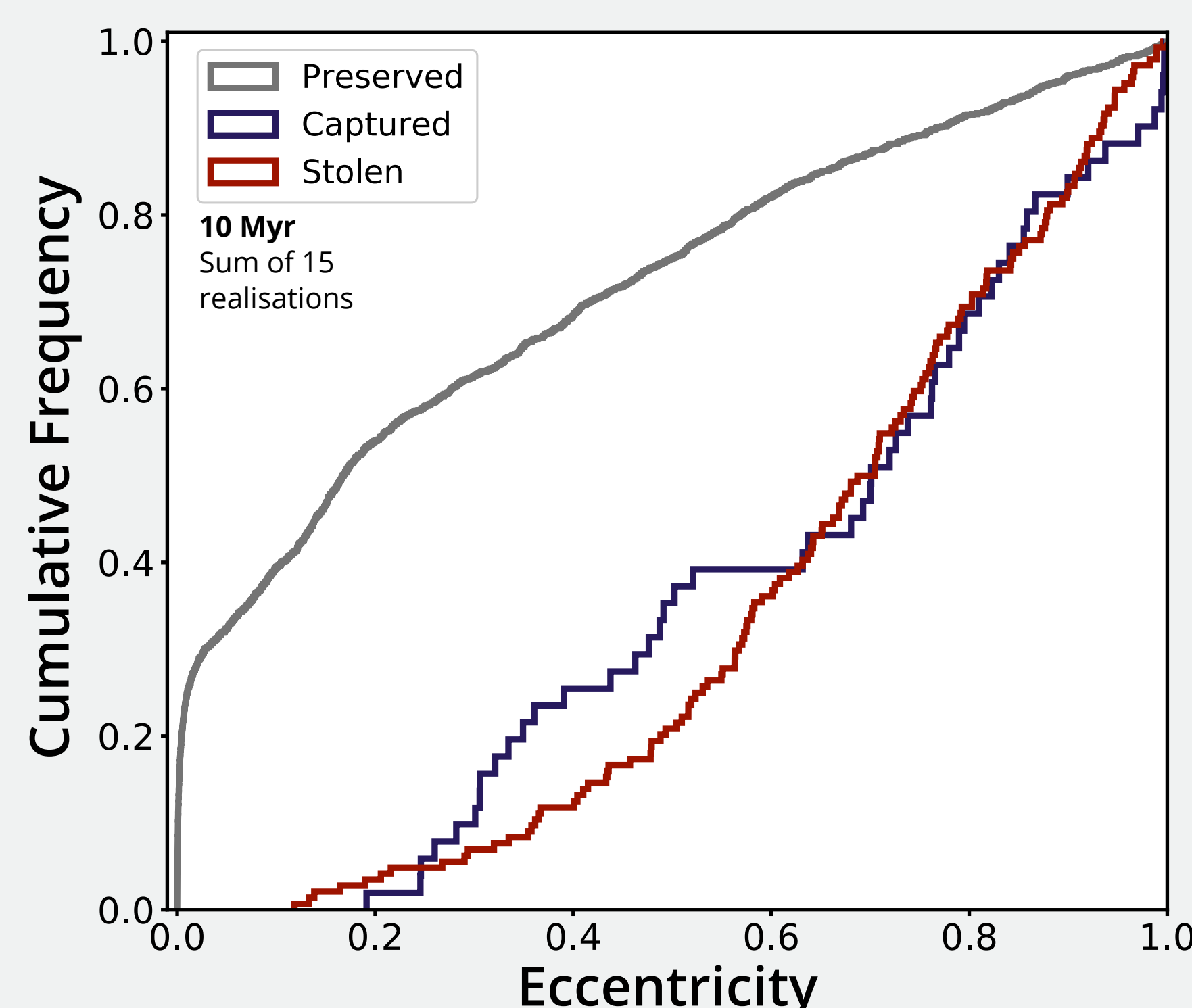
Semimajor Axis

- Stolen planets have a different semimajor axis distribution to captured planets.
- But a very similar distribution to preserved planets (that are still orbiting their original star). This would make them harder to distinguish observationally based on semimajor axis.



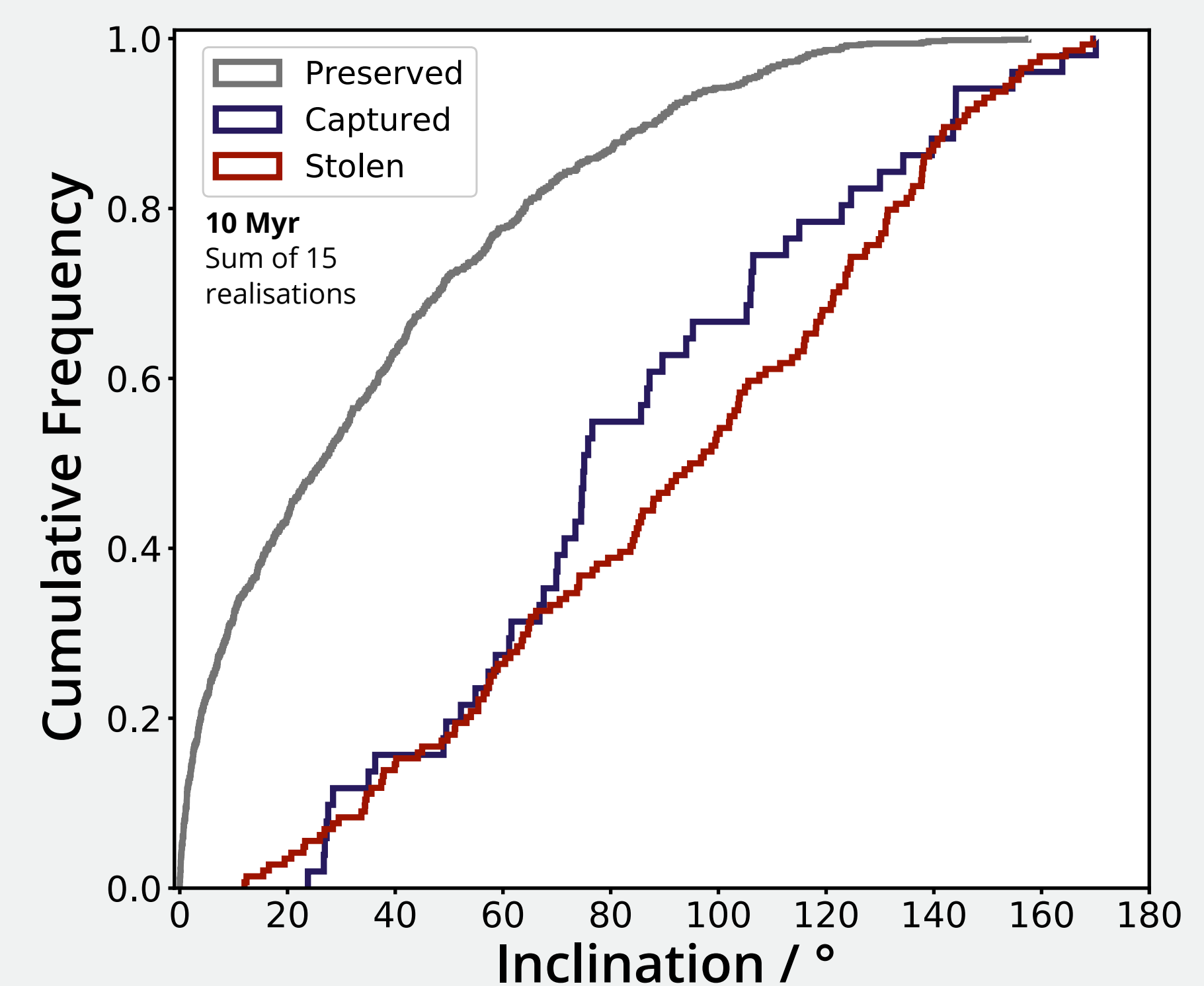
Eccentricity

- Preserved planets have a very different eccentricity distribution to those that have been captured or stolen.
- Planet 9's eccentricity could be used to determine whether it most likely formed in the Solar System.
- Any difference between stolen and captured planets?



Inclination

- Planets are stolen and captured onto orbits with approximately random inclinations.
- Theft can produce inclinations similar to that of Planet 9.
- Any difference between stolen and captured planets?



Conclusions

- Dynamical interactions between stars and planetary systems are common in star-forming regions.
- Planet theft is one of these dynamical interactions - where a planet is directly exchanged between stars during an encounter.
- Planet theft is significant in dense young star-forming regions. And may even be more frequent than the capture of free-floating planets.
- Theft can create similar orbits to that of the hypothetical 9th planet in the Solar System, as well as observed exoplanets with unusually wide orbits > 1000 AU.

Future Work

- Expand parameter space.
- Analyse and quantify how different the orbits of stolen, captured, and preserved planets are. And how these differ for different initial conditions.

References

- [1] Deacon et al, 2016, MNRAS, 457, 3191-3199
- [2] Mustill et al, 2016, MNRAS, 460, L109-L113
- [3] Batygin & Brown, 2016, AJ, 151, 22-34
- [4] Batygin & Brown, 2016, AJ, 824, L23
- [5] Lada & Lada, 2003, ARAA, 41, 57
- [6] Gieles, Moeckel & Clarke, 2012, 426, L11
- [7] Adams, 2010, ARAA, 48, 46
- [8] Parker & Quanz, 2012, MNRAS, 419, 2448