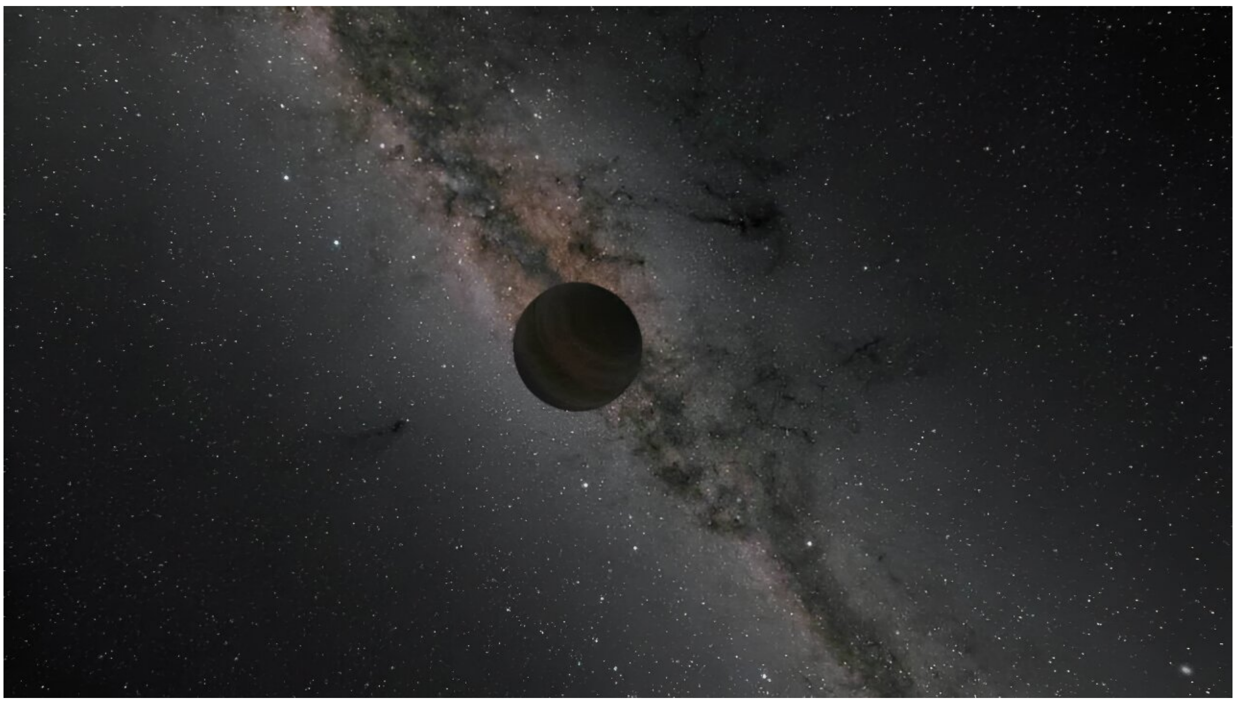
Where are all these rogue planets coming from?

April 2 2024, by Evan Gough



An artist's illustration of a rogue planet, dark and mysterious. Credit: NASA

There's a population of planets that drifts through space untethered to any stars. They're called rogue planets or free-floating planets (FFPs.) Some FFPs form as loners, never having enjoyed the company of a star. But most are ejected from solar systems somehow, and there are different ways that can happen.

One researcher set out to try to understand the FFP population and how they came to be.

FFPs are also called isolated planetary-mass objects (iPMOs) in scientific literature, but regardless of what name's being used, they're the same thing. These planets wander through interstellar space on their own, divorced from any relationship with stars or other planets.

FFPs are mysterious because they're extremely difficult to detect. But astronomers are getting better at it and are getting better tools for the task. In 2021, astronomers made a determined effort to detect them in Upper Scorpius and Ophiuchus and detected 70 of them, possibly many more.

In broad terms, there are two ways FFPs can form. They can form like most planets do, in protoplanetary disks around young stars. These planets form by accretion of dust and gas. Or they can form like stars do by collapsing in a cloud of gas and dust unrelated to a star.

For planets that form around stars and are eventually kicked out, there are different ejection mechanisms. They can be ejected by interactions with their stars in a binary star system, they can be ejected by a stellar flyby, or they can be ejected by planet-planet scattering.

In an effort to understand the FFP population better, one researcher examined ejected FFPs. He simulated rogue planets that result from planet-planet interactions and those that come from binary star systems, where interactions with their binary stars eject them. Could there be a way to tell them apart and better understand how these objects come to be?

This image shows the locations of 115 potential rogue planets, highlighted with red circles, recently discovered in 2021 by a team of astronomers in a region of the sky occupied by Upper Scorpius and Ophiucus. The exact number of rogue planets found by the team is between 70 and 170, depending on the age assumed for the study region. This image was created assuming an intermediate age, resulting in a number of planet candidates in between the two extremes of the study. Credit: ESO/N. Risinger (skysurvey.org)

A new paper titled "On the properties of free-floating planets originating in circumbinary planetary systems" tackled the problem. The author is Gavin Coleman from the Department of Physics and Astronomy at Queen Mary University of London. The paper will be published in the *Monthly Notices of the Royal Astronomical Society* and is available on the *arXiv* preprint server.

In his paper, Coleman points out that researchers have explored how FFPs form, but there's more to do. "Numerous works have explored mechanisms to form such objects but have not yet provided predictions on their distributions that could differentiate between formation mechanisms," he writes.

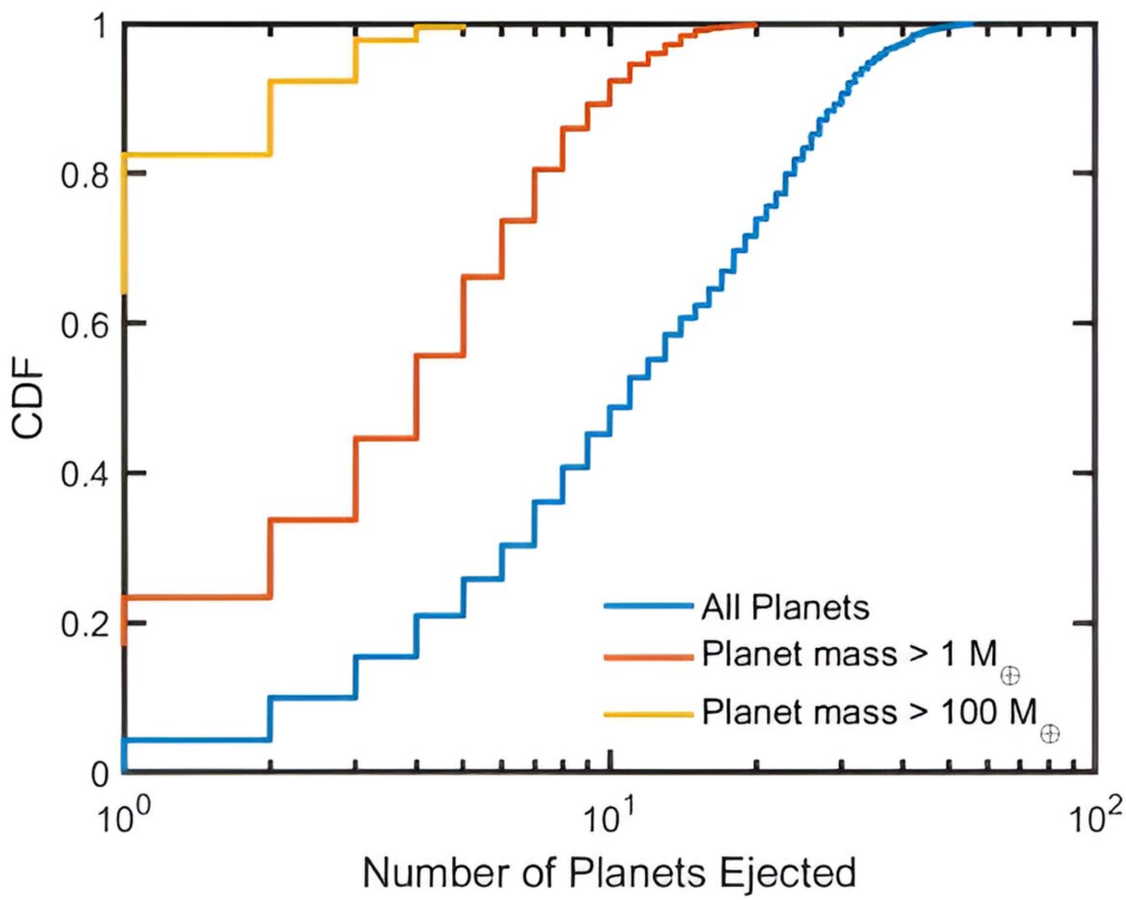
Coleman focuses on ejected stars rather than stars that formed as rogues. He avoids rogue planets that are a result of interactions with other planets because planet-planet scattering is not as significant as other types of ejections. "It is worth noting that planet-planet scattering around single stars cannot explain the large number of FFPs seen in observations," Coleman explains.

Coleman singles out binary star systems and their circumbinary planets in his work. Previous research shows that planets are naturally ejected from circumbinary systems. In his research, Coleman simulated binary star systems and how planets ejected from these systems behave. "We find significant differences between planets ejected through planet-planet interactions and those by the binary stars," he writes.

Coleman based his simulations on a binary star system named TOI 1338. TOI 1338 has a known circumbinary planet called BEBOP-1. Using a known binary system with a confirmed circumbinary planet provides a solid basis for his simulations. It also allowed him to compare his results with other simulations based on BEBOP-1.

The simulation varied several parameters: the initial disk mass, the binary separation, the strength of the external environment, and the turbulence level in the disk. Those parameters strongly govern the planets that form. Other parameters used only a single value: the combined stellar mass, mass ratio and binary eccentricity. The combined stellar mass of TOI 1338 is about 1.3 solar masses, in line with the average in binary systems of about 1.5 solar masses.

Each simulation ran for 10 million years, long enough for the solar system to take shape.



This figure from the paper shows the masses of ejected planets. The blue line represents all planets, the red line represents planets with less than 1 Earth mass, and the yellow line represents huge planets with greater than 100 Earth masses. Credit: Coleman 2024.

Coleman found that circumbinary systems produce FFPs efficiently. In the simulations, each binary system ejects an average of between two to seven planets with greater than 1 Earth mass. For giant planets greater than 100 Earth masses, the number of ejected planets drops to 0.6 planets ejected per system.

The simulations also showed that most planets are ejected from their circumbinary disks between 0.4 to 4 million years after the beginning of the simulation. At this age, the circumbinary disk hasn't been dissipated and blown away.

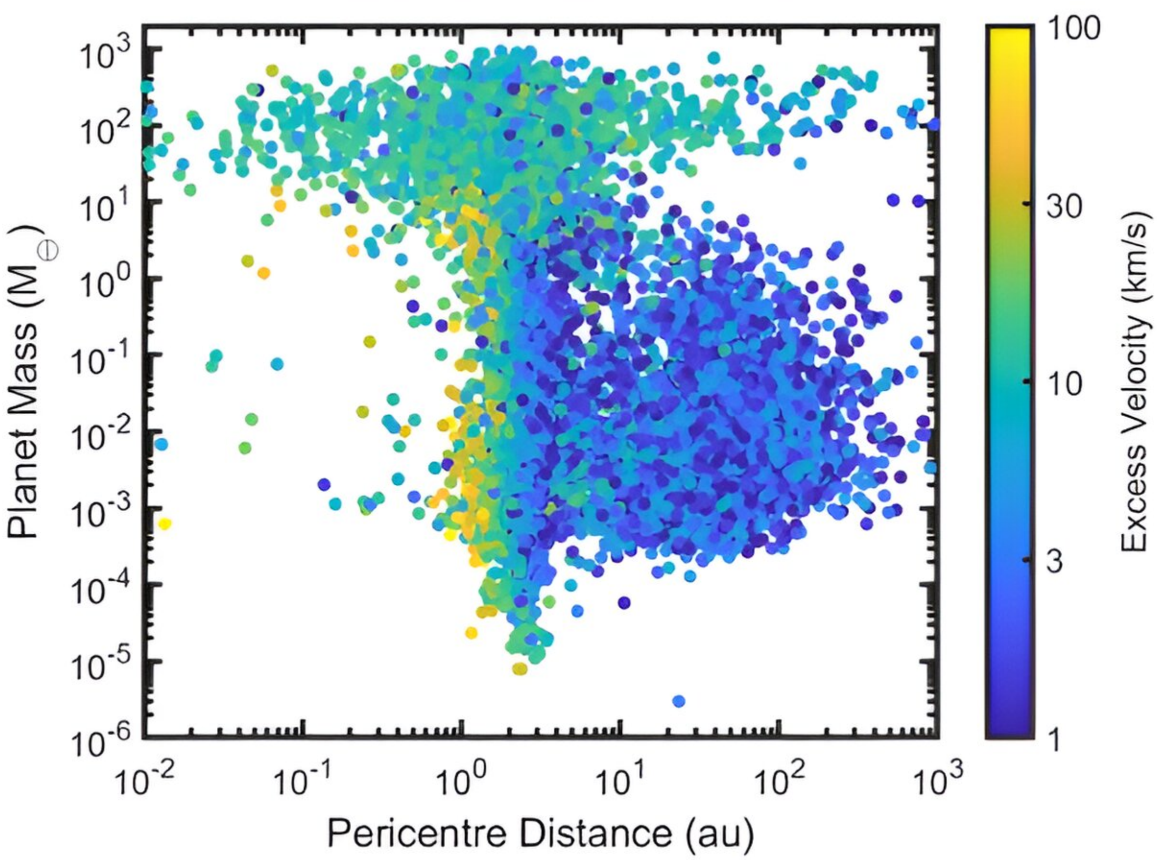
The most important result might concern the velocity dispersions of FFPs. "As the planets are ejected from the systems, they retain significant excess velocities, between 8–16 km/s. This is much larger than observed velocity dispersions of stars in local star-forming regions," Coleman explains. So this means that the velocity dispersions of FFPs can be used to tell ejected ones from ones that formed as loners.

The velocity dispersions provide another window into the FFP population. Coleman's simulations show that the velocity dispersion of FFPs ejected through interactions with binary stars is about three times larger than the dispersion from planets ejected by planet-planet scattering.

Coleman also found that the level of turbulence in the disk affects planet ejection. The weaker the turbulence is, the more planets are ejected. Turbulence also affects the mass of ejected planets: weaker turbulence ejects less massive planets, where about 96% of ejected planets are less than 100 Earth masses.

Taken together, the simulations provide a way to observe the FFP population and to determine their origins. "Differences in the distributions of FFP masses, their frequencies, and excess velocities can all indicate whether single stars or circumbinary systems are the fundamental birthplace of FFPs," Coleman writes in his conclusion.

But the author also acknowledges the drawbacks in his simulations and clarifies what the sims don't tell us.



This figure shows the excess velocity of the ejected FPP population in the simulations. The color-coded bar on the right shows the amount of excess velocity. The x-axis shows the pericenter distance because it "gives an approximate location for the final interaction that led to the ejection of the planet," according to the author. Credit: Coleman 2024

"However, while this work contains numerous simulations and explores a broad parameter space, it does not constitute a full population of forming circumbinary systems," Coleman writes in his conclusion. According to Coleman, it's not feasible with current technology to derive a full population of these systems.

"Should such a population be performed in future work, then comparisons between that population and observed populations would give even more valuable insight into the formation of these intriguing objects," he explains.

There's still a lot astronomers don't know about binary systems and how they form and eject planets. For one thing, models of planet formation are constantly being revised and updated with new information.

We also don't have a strong idea of how many FFPs there are. Some researchers think there could be trillions of them. The upcoming Nancy Grace Roman space telescope will use gravitational lensing to take a census of exoplanets, including a sample of FFPs with masses as small as Mars'.

In future work, Coleman intends to determine if there are chemical composition differences between FFPs. That would constrain the types of stars they form around and where in their protoplanetary disks they formed. That would require spectroscopic studies of FFPs.

But for now, at least, Coleman has developed an incrementally better way to understand FFPs. Using this data, astronomers can begin to discern where individual FFPs came from and to better understand the population at large.

More information: Gavin A. L. Coleman, On the properties of free floating planets originating in circumbinary planetary systems, *arXiv* (2024). DOI: 10.48550/arxiv.2403.18481

Provided by Universe Today

Citation: Where are all these rogue planets coming from? (2024, April 2) retrieved 2 May 2024 from https://phys.org/news/2024-04-rogue-planets.html