A Quantitative Criterion for Defining Planets. Jean-Luc Margot[1], [1]University of California, Los Angeles, 595 Charles E. Young Drive East, Los Angeles, CA 90095 (jlm@epss.ucla.edu).

Introduction: A simple metric can be used to determine whether a planet or exoplanet can clear its orbital zone during a characteristic time scale, such as the lifetime of the host star on the main sequence. This criterion requires only estimates of star mass, planet mass, and orbital period, making it possible to immediately classify 99% of all known exoplanets. All 8 planets and all classifiable exoplanets satisfy the criterion. This metric may be useful in generalizing and simplifying the definition of a planet.

Existing Definition: In 2006, the International Astronomical Union (IAU) adopted resolution B5, which states: "A planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit."

Proposed Metric: A simple metric [1] allows for the quantification of the third requirement and the extension of the definition to planets orbiting other stars. It is possible to write down the mass required for a planet to evacuate its orbital zone out to a specific distance in a specific time scale, hereafter the orbit-clearing mass. The extent of the orbital zone is chosen to be a number of Hill radii, and the time scale is chosen to be the lifetime of the host star. The proposed metric is robust as it is not very sensitive to these choices (Fig.1). It is easy to implement as it requires only estimates of star mass, planet mass, and orbital period, all of which are observable from Earth.

Planet Test: The symbol Π represents the mass of a planetary body in terms of the corresponding orbit-clearing mass: $\Pi = M_{\text{body}} / M_{\text{clear}}$.

A simple planet test consists of evaluating whether the discriminant Π exceeds 1. All 8 planets and all classifiable exoplanets satisfy the criterion (Figs. 1, 2).

Dynamical Dominance: It must be emphasized that a planet can never completely clear its orbital zone, because gravitational and radiative forces continually perturb the orbits of asteroids and comets into planet-crossing orbits, and because planets can capture small bodies in tadpole, horseshoe, and quasi-satellite orbits near the Lagrange equilibrium points. What the IAU intended is not the impossible standard of impeccable orbit clearing; rather the standard is analogous to a *dynamical-dominance* criterion. The dynamical-dominance language may be less prone to misinterpretation.

On Roundness: The orbit-clearing criterion provides a quantifiable criterion that addresses the first and third aspects of the 2006 IAU planet definition. A separate issue is whether the second requirement, i.e., roundness, is necessary. Because roundness is usually not observable from Earth nor easily quantifiable, it is inherently problematic as a basis for classification. It turns out that every object that can clear its orbital zone is "nearly round" [1], which makes it possible to simplify and strengthen the definition of a planet by removing the roundness requirement.

Possible Improvements to the Planet Definition: One possible formulation is as follows: "A planet is a celestial body that (a) is in orbit around one or more stars or stellar remnants, (b) has sufficient mass to clear [or dynamically dominate] the neighborhood around its orbit, i.e., $\Pi \geq 1$, (c) has a mass below 13 Jupiter masses, a nominal value close to the limiting mass for thermonuclear fusion of deuterium. For single-star systems, $\Pi \geq 1$ when

$$\frac{M_p}{M_\oplus} \gtrsim 1.2 \times 10^{-3} \left(\frac{M_\star}{M_\odot} \right)^{5/2} \left(\frac{a_p}{1\,\text{au}} \right)^{9/8} ,$$

where M is mass, a is semi-major axis, and subscripts $p, \star, \oplus, \odot$ refer to the planet, star, Earth, and Sun, respectively."

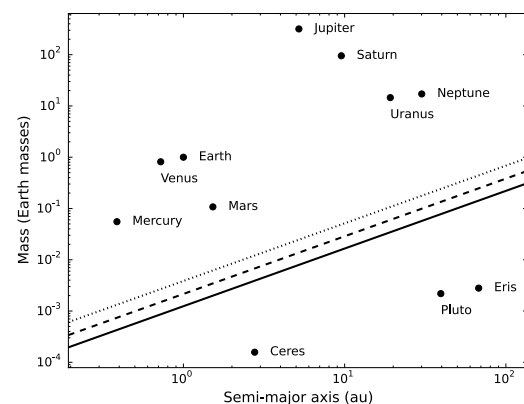**Reference:**
[1] Margot J. L. (2015) AJ, 150, 185.

Fig. 1: Mass required to clear an orbital zone as a function of semi-major axis for a host star of one solar mass. The top two lines show clearing to 5 Hill radii in either 10 billion years (dashed line) or 4.6 billion years (dotted line). The solid line shows clearing of the feeding zone ($2(3)^{1/2}$ Hill radii) in 10 billion years.
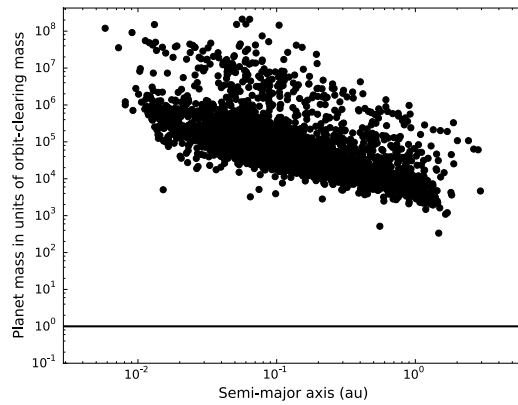
Fig. 2: Planet test applied to 4276 Kepler objects categorized as either "confirmed" or "candidate" in the NASA Exoplanet Archive. All objects have a mass that exceeds the mass required to clear the corresponding orbital zone over the lifetime of the host star on the main sequence ($\Pi \geq 1$). Results are robust against the choice of the radius-mass relationship.