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Making sense of the exoplanet zoo

The diversity of substellar objects may call for a rethinking of our labeling conventions

By **Rebecca Oppenheimer**

The regions around stars on length and mass scales similar to that of our own solar system are relatively new to human exploration. In the two decades since "substellar objects," things less massive than stars, were discovered orbiting stars other than the Sun, the single most certain statement about them has been "expect the unexpected." On page 673 of this issue, Wagner *et al.* (*1*) reinforce that statement by reporting on the detection of a substellar object orbiting within a triple-star system.

Although a number of other substellar objects have been observed in triple-star systems (*2*–*5*), the one reported by Wagner *et al.* is particularly interesting because it must be influenced by the gravitational pull of the other two stars, causing an improbable orbit. In fact, this small object, somewhat more massive than Jupiter, yet very young (~16 million years), could well be in an unstable orbit. It could be thrown out into space to drift alone. Many such solitary objects, some perhaps rejected from their natal solar systems, are being discovered routinely (*6*). All are different from each other, straining current classification schemes.

Another star, one of thousands now discovered, that exhibits the "unexpected" and draws into question what constitutes a solar system is HD 41004. It is somewhat smaller than the Sun, with an object 2.5 times as massive as Jupiter on an orbit slightly more than Earth's about the Sun. In addition, another star orbiting HD 41004, at the equivalent of Uranus's orbit, has a substellar object orbiting it with about 20 times the mass of Jupiter (*4, 5*). So, is our labeling of HD 41004 as a "solar system" accurate even though it contains two stars, an exoplanet, and a brown dwarf (an object intermediate between a star and a planet)? Also, is that brown dwarf actually a moon of the smaller star? The more general question to ask our-

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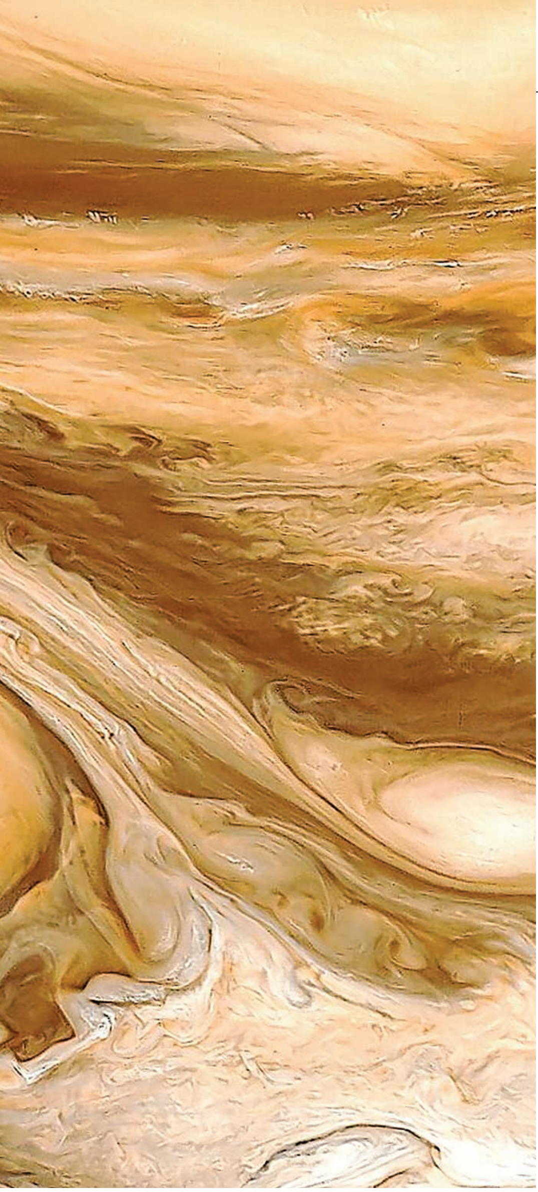
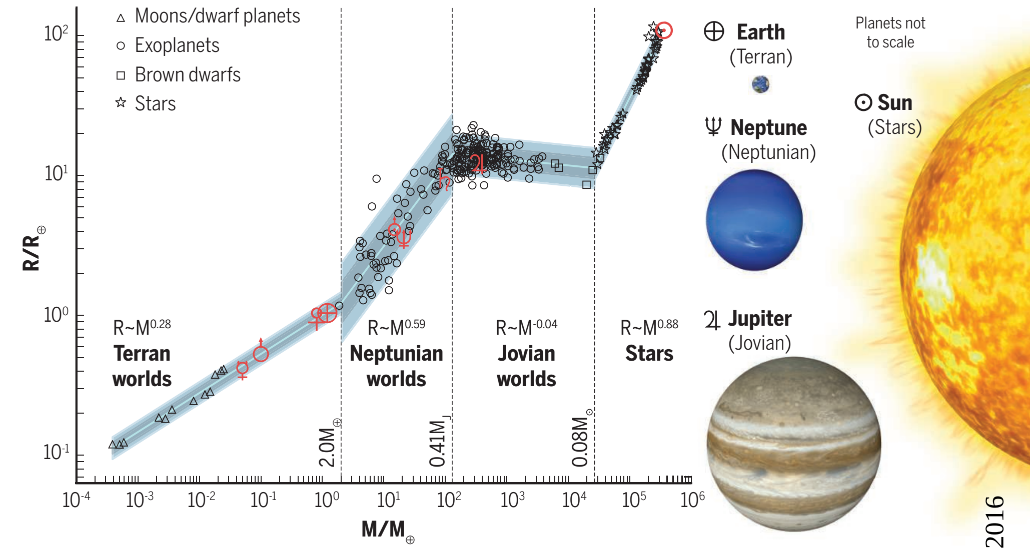


Jupiter's Great Red Spot. A snapshot of the swirling dynamics of the Jovian planet's atmosphere. But, what characteristics define other substellar objects?



Cataloging categories. Mass-radius relation for objects generally referred to as planets, brown dwarfs, and stars [reproduced from (*10*)]. Our current classification schemes using terms such as "exoplanet," "brown dwarf," or "star" may be of limited value for scientific understanding. Radius is represented in units of Earth radii, and mass in units of Earth mass. The historical signs (red) represent the various planets of our solar system. The apparent scarcity of "brown dwarfs" (black squares) is simply because few have well-measured masses and radii, although thousands have been found.

selves is what these words actually mean.

Categorizing is an age-old practice in scientific thought. Labels imply meaning and assign properties to things, so that they can be discussed efficiently. However, after 22 years of working on substellar objects, I suspect that these categories may have lost their utility in advancing knowledge (*7*). Labels can become obfuscating jargon.

To study in isolation what we call stars, brown dwarfs, planets, moons, or even dwarf planets implies that they are intrinsically unrelated entities. Perhaps this is understandable: As searches for substellar objects continue, the enormous diversity in salient properties appears as one examines objects of smaller mass. Every single object requires its own explanation through many parameters (*8*). Age, chemical composition, mass, temperature, irradiation from a nearby star—all of these factors, and others, determine what an object looks like. Some young substellar objects even look like old stars (*1, 5, 6, 8*). In contrast, stars, if one can measure their brightness and distance, reveal their mass, and how they live their lives, with particular certainty (*9*). With fascinating discoveries, such as Wagner *et al.*'s new "planet" in a triple-star system, and the thousands of objects intermediate between it and stars, what we know is that they consistently fail to conform to the stellar classification system intrinsic to the history of astrophysics (*8*). In such a confusing situation, the best we can do is to rethink the basic assumptions.

Some scientists are doing just that, and perhaps revealing relationships between these seemingly disparate substellar objects. The most fundamental parameters that we can measure for substellar objects are their mass and radius. Chemical composition, temperature, and orbits are also measurable, but individual objects can evolve (and do) with respect to these quantities. Mass and radius are more constant (except radius at very young ages). Both are extremely difficult to measure, but we are now beginning to amass precise measurements for hundreds of objects.

From the accurately known masses and radii of substellar objects, it is clear that there are different groupings (see the figure) (*10*). Massive objects that fuse hydrogen (stars) have a different relation between mass and radius than lower-mass objects that cannot sustain long-term nuclear fusion. The lower the mass of those objects, the larger they are (analogs to Jupiter, including what are called brown dwarfs and exoplanets). At even lower masses, worlds like Neptune follow a different relation and are smaller at smaller masses. At the lowest masses, solid objects like Earth and the Moon behave like objects we tend to know in everyday life—they are hard, smaller, and less massive. Chen and Kipping (*10*) propose a new nomenclature based on these observed measurements: Jovian, Neptunian, and Terran worlds. Whether this scheme is useful will certainly be debated, but it is a fresh alternative to the confusing terms in use today.

Perhaps it is too early to define classes of objects inhabiting our universe's vast zoo of diverse solar systems. To do so may obscure their commonalities and differences, urging overspecialization in the study of objects assumed to be unrelated because of thought-constraining labels. The new system of objects described by Wagner *et al.* serves as a reminder that the universe is full of unexpected phenomena. ■

GRAPHIC: C. BICKEL/SCIENCE

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