Part 10

Panel Discussion of Substellar Terminology

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Brown Dwarfs
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Nomenclature: Brown Dwarfs, Gas Giant Planets, and ?

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Abstract. The question of what sort of guidelines should be used to classify substellar mass objects was considered and debated during an evening panel discussion at the IAU 211 Symposium on Brown Dwarfs.

1. Alan P. Boss, Panel Chair

1.1. Introduction

The discovery of free-floating objects in regions of recent star formation with masses inferred to be less than the deuterium-burning limit of $\sim$13 $M_{\rm Jup}$ has sparked a lively debate over what these objects should be called. At the same time, the discovery of very low mass companions to solar-type stars by spectroscopic surveys has uncovered a plethora of objects with minimum masses in the range from $\sim$0.1 $M_{\rm Jup}$ to $\sim$15 $M_{\rm Jup}$. While most of the latter objects can be universally agreed upon to be worthy of the appellation "planet," some of these companions will likely have true masses above the deuterium-burning limit, calling into question their proper classification.

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1.2. Evening Panel Discussion

An evening session at IAU 211 was devoted to the topic of nomenclature of very low mass objects. Brief presentations were given by several distinguished members of the brown dwarf community: Gibor Basri, Shiv Kumar, James Liebert, Maria Rosa Zapatero Osorio, Didier Queloz, and Bo Reipurth, followed by comments by the panel chair, Alan Boss. These formal presentations were followed by ample feedback from the audience. A great variety of opinions were offered, but it was unclear if there was a single, majority opinion. The strong attendance at this evening session suggests that the question of nomenclature is one which continues to stir the interests and passions of astronomers working in this burgeoning, new area of research.

1.3. Definition of the Working Group on Extrasolar Planets

A working definition developed by the IAU Working Group on Extrasolar Planets promises to fully satisfy no one, because it is a compromise reached by a group with diverse views, but it can serve as a basis for modifying the definitions of "planets" and "brown dwarfs" as further observational information is gathered.

The IAU Working Group on Extrasolar Planets (WGESP) consists of thirteen members: Alan Boss (chair), R. Paul Butler, William B. Hubbard, Philip A. Ianna, Martin Kürster, Jack J. Lissauer, Michel Mayor, Karen Meech, Francois Mignard, Alan J. Penny, Andreas Quirrenbach, Jill C. Tarter, and Alfred Vidal-Madjar. Being charged with overseeing IAU activities in the area of extrasolar planets, the WGESP realized that some sort of definition would be needed regarding what should be termed a "planet," and what should not, based on what is presently known. After several months of deliberations, on February 28, 2001, the WGESP agreed upon the following position statement regarding a working definition for a "planet."

Rather than try to construct a detailed definition of a planet which is designed to cover all future possibilities, the WGESP has agreed to restrict itself to developing a working definition applicable to the cases where there already are claimed detections, e.g., the radial velocity surveys of companions to (mostly) solar-type stars, and the imaging surveys for free-floating objects in young star clusters. As new claims are made in the future, the WGESP will weigh their individual merits and circumstances, and will try to fit the new objects into the WGESP definition of a "planet," revising this definition as necessary. This is a gradualist approach with an evolving definition, guided by the observations that will decide all in the end.

Emphasizing again that this is only a working definition, subject to change as we learn more about the census of low-mass companions, the WGESP has agreed to the following statements:

1. Objects orbiting around solar-type stars with true masses above the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) are "brown dwarfs" (no matter how they formed), while objects with true masses below this limiting mass are "planets."

2. Free-floating objects in young star clusters (which presumably formed in the same manner as stars and have not been shown to be ejected from plane-

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tary systems) with masses below the limiting mass for thermonuclear fusion of deuterium are not "planets," but are "sub-brown dwarfs" (or whatever name is most appropriate).

These statements are a compromise between definitions based purely on the deuterium-burning mass or on the formation mechanism, and as such do not fully satisfy anyone on the WGESP. However, the WGESP agrees that these statements constitute the basis for a reasonable working definition of a "planet" at this time. We can expect this definition to evolve as our knowledge improves.

Note that these statements are restricted to extrasolar planets and are not intended to address the question of a possible lower mass limit for "planets" in our Solar System.

2. Gibor Basri

I have thought a lot about this issue, and have been able to condense my thoughts into a description of the arenas in which I think definitions of "planet" are being attempted. Most of the controversies we have arise from different choices of emphasis within these arenas. In particular, the main two camps come from the "characteristics" vs. "cosmogony" arenas, which are largely orthogonal. The use of "circumstance" is not needed by "characteristics" purists, but many astronomers (and the lay public) seem to feel that planets should be orbiting something. Briefly, the three arenas are as follows:

Characteristics (*physical attributes*): (1) Properties of size and shape (pressure support mechanisms); (2) the source of luminosity (internal energy source).

Circumstances (*orbital attributes*): (1) What sort of central body is being orbited; (2) the shape, size, and tilt of the orbit; (3) dynamical importance of the orbit (is the orbit "shared").

Cosmogony (*the mode of formation in a disk*): (1) Were planetesimals a necessary pre-condition to the formation of the object? (2) Was a protoplanetary disk a necessary pre-condition to the formation of the object?

It is my opinion that cosmogony should be left out of the definition because (1) we don't know enough about all modes of planetary formation, (2) it is very difficult to ascertain much about it observationally, and (3) stars, brown dwarfs, and planets all form with disks as an integral part of the process, and all likely accrete planetesimals as part of their formation (but clearly with different levels of importance of that process). The panel discussion was controversial largely because some members of the panel and audience insisted on cosmogony as a primary part of the definition, while others disagreed.

I offer the following proposed definitions as the most reasonable solution of this issue (but obviously not everyone agrees with me): (1) A **fusor** is an object that is capable of core fusion sometime during its lifetime. (2) A body has **planetary mass** if it is a spherical non-fusor. (3) A **planet** is a body with planetary mass which was born in orbit around a fusor.

It is also natural and desirable that planet can have qualifiers, such as : *historical* (the usual nine, maybe adding Ceres); *minor* (those not in dynamically important orbits); *terrestrial, icy, gas giant, ordinary, degenerate or super* (structural or compositional qualifiers); *agglomerated, core-accretion, direct collapse*

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(cosmogenetic qualifiers which may be hard to confirm); *ejected or captured* (this must be established or favored empirically). Moons can have planetary mass, but are not planets (a binary planet has its center-of-mass outside both bodies). It may be of interest to note that with these definitions, both Pluto and Ceres are best called *minor planets.*

3. Shiv S. Kumar

As I have repeatedly pointed out, the processes of star formation are fundamentally different from those of planet formation (Kumar 1964, 1967, 1974, 1990, 2003). Stars are, in general, formed by the fragmentation of interstellar or primordial clouds, whereas planets generally are formed by the slow accumulation (accretion) of dust, rocks, and gas in the vicinity of a star. The stellar domain, which exists independent of the planetary domain, may extend down to mass of $\sim$0.001 $M_\odot$ (or $\sim$1 $M_{\rm Jup}$). In the planetary domain, the maximum mass of an object formed by the planet formation processes (in the vicinity of a star of any mass) is $\sim$2 $M_{\rm Jup}$ (Kumar 2003).

In the past few years, quite a few people in the scientific community have referred to the luminous and dark objects with mass below 0.013 $M_\odot$ (the so-called deuterium-burning limit) as "planets," but that, frankly speaking, is illogical. Just because a gaseous object of mass 0.01 $M_\odot$, formed by the star formation processes, doesn't go through deuterium-burning reactions doesn't mean that it's fundamentally different from a gaseous object of mass 0.015 $M_\odot$ formed by the same formation mechanism. The destruction of deuterium in the interior of a young, contracting, very-low-mass gaseous object doesn't change its structure or its final destiny; all it does is slow down its evolution a bit (Kumar 1963b). Whether or not they go through deuterium burning, all hydrogen-rich, very-low-mass gaseous objects (with mass below the Kumar limit of $\sim$0.08 $M_\odot$) quickly end up as completely degenerate objects (Kumar 1963a).

Since deuterium burning is irrelevant to determining the basic nature of a very-low-mass luminous or dark object, we have to look at other characteristics such as its age, its atmospheric chemical composition, its internal structure and composition, its motion, etc., to ascertain its formation mechanism. The determination of the basic nature of an object solely based on its mass is likely to lead to incorrect conclusions. Let us, for example, briefly look at the case of the dark companion to the G0 star HD 106252. Fischer et al. (2002) find that the dark companion has a minimum mass of 0.007 $M_\odot$, an orbital eccentricity of 0.57, and a semi-major axis of 2.42 AU. With these properties, the HD 106252 system appears to be more like a double star system than a star-planet system. In other words, HD 106252b is unlikely to have originated as a planet. The same conclusion may be drawn about many of the other dark companions that are being called "extrasolar planets."

4. James Liebert

Mass-based (or nuclear theory-based) definitions for stars, brown dwarfs, and giant planets make some sense, because often one can estimate/measure the mass (i.e., if an astrometric binary, or in a cluster of known age and distance).

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Stellar evolution theory including the reactions for hydrogen-burning has long been used to differentiate a brown dwarf from a low-mass star, once the mass and composition are known. I have the sense that most people at this symposium choose the deuterium-burning limit (13 $M_{\rm Jup}$) as the boundary between brown dwarfs and planets, regardless of whether they are in orbit around a star.

Formation theory–based definitions are, in my opinion, precarious and best avoided. One doesn't know if apparently "free-floating" planets which may have recently been discovered in Orion formed by self-collapse or by formation in a disk followed by ejection (Reipurth 2003). Likewise, we don't know whether the late L brown dwarf companion to an M8 dwarf at ~5 AU separation (Freed, Close, & Siegler 2003) formed in a relatively massive accretion disk or like a binary companion star. Theorists would bet heavily on the latter, but my contention is that stellar nuclear theory is on a firmer foundation than star, disk, and planet formation theory.

There is actually a third possible property to distinguish stars, brown dwarfs, and giant planets not discussed in the open discussion but which I will mention here: The definitions might be distinguished by a change in the dominant pressure term in the interior equation-of-state (EOS). At the hydrogen-burning mass limit, the EOS changes from domination by ideal gas and coulomb interactions (very low mass star) to substantial electron degeneracy pressure (a cool brown dwarf). The stars get smaller with decreasing mass down to 75–80 $M_{\rm Jup}$. Then, due to the dominance of nonrelativistic degeneracy, the radius of the brown dwarf increases with decreasing mass, though more slowly than for a white dwarf. However, the radius reaches a maximum at the mass of about 4 $M_{\rm Jup}$. (See for instance the radius-mass plot in Figure 1 of Burrows & Liebert 1993.) Below this mass the EOS for a cold object has a more complicated form appropriate to metallic hydrogen, and the radius again decreases with decreasing mass. The argument is that the interiors of cold 5–12 $M_{\rm Jup}$ entities have EOS physics more similar to that of 13–75 $M_{\rm Jup}$ brown dwarfs than that of Jupiter—brown dwarfs span the larger interval of 5–75 $M_{\rm Jup}$.

5. Eduardo L. Martín

Research on substellar mass objects outside the Solar System has been really astounding in the last few years. With the flurry of observational discoveries, some of our most deeply embedded ideas are changing. It should be no surprise, confusion is a healthy sign of a rapidly developing young age. We must be prepared to abandon preconceived ideas and have a fresh look at the new data. Substellar-mass companions have been revealed around neutron stars, white dwarfs, stars all over the H-R diagram, and brown dwarfs.

The IAU working group on substellar terminology has provided a working definition of what to call a brown dwarf and what to call a planet. Such working definition was debated during an evening panel discussion chaired by Alan Boss at IAU Symposium 211. I think the result was that there is not a consensus about adopting the IAU working group suggestion. Many interesting ideas were discussed and most of them are included in this book. All attendees to the meeting were invited to contribute their views for the proceedings. Those who responded are co-authors of this paper.

Here I summarize some of the observational results presented in IAU211 that I consider most relevant for our discussion on substellar terminology: The mass function of companions has been characterized for very limited conditions, for example the close environments of solar-type stars (separations < 3 AU) and the distant surroundings around cool stars (separations > 100 AU). It seems that brown dwarfs could be more common at large separations (Gizis; Potter, Martín & Cushing), although this is not entirely clear (McCarthy, Zuckerman & Becklin). Substellar-mass objects down to the detection limits of deep imaging surveys have been revealed, although a possible minimum mass cutoff may have been detected in Trapezium cluster (Lucas, Roche & Riddick). The masses inferred from isochrone fitting go down to about 3 $M_{\rm Jup}$ (Zapatero Osorio et al.). The mass function of free-floating substellar objects is different than that of substellar companions to stars **at small separations**. The situation is unclear for large separations. The brown dwarfs themselves appear to have a tendency for being binaries with nearly-equal masses (Bouy et al.; Close, Siegler & Freed).

From the theoretical point of view, the work presented in this conference revealed that there are several mechanisms to form substellar objects with masses down to about 1 $M_{\rm Jup}$. Fragmentation with magnetically-induced rebound (Boss), formation in unstable disks (Bate, Bonnell & Bromm), ejection in unstable multiple systems (Delgado-Donate & Clarke; Reipurth & Clarke), migration in disks (Armitage & Bonnell). There are no physical reasons why substellar objects cannot form in different ways.

Finally, I come to the sticky questions of this debate. What to call a brown dwarf and what to call a planet. We unanimously agreed in the 1997 conference held in Tenerife that Teide 1 is a brown dwarf, and nobody would call Jupiter otherwise than planet, but what about intermediate cases? Is Gl229B a planet or a brown dwarf? If Gl229B has a companion, would it be a planet, a moon or something else? How should we call free-floating objects with masses comparable to Jupiter, Saturn or even the Earth? Does everyone agree with the title of the Guenther & Wuchterl paper which implies that planets could orbit brown dwarfs (cf. Basri in this discussion)?, etc, etc

I will not offer a set of rules here because I think it is premature on the basis of our current observational knowledge and theoretical understanding of extrasolar substellar-mass objects. Passions seem to be arisen over what is a planet and what is not. We must not decide any scientific nomenclature under the influence of the juvenile passion of a field that is amidst the effervescence of scientific discovery. Usage rather than logic frequently shapes our language. For now I will continue calling brown dwarfs those objects with masses above the deuterium burning limit, and planets those with lower masses. For me, objects with planetary masses which are not orbiting a star are free-floating planets.

6. Bo Reipurth

Astronomy is populated by categories of objects with names that are succinct (*pulsars*), curious (*red supergiants*), or misleading (*planetary nebulae*). But whatever the category, as the above examples show, once an informal name has taken hold it is rarely displaced, even when subsequent research shows that it is a misnomer. Therefore, although *brown dwarfs* is in the last category, the name is not likely to go away. That is fine, except that we are now facing the question of where brown dwarfs end and giant planets begin. It is a scientifically interesting question, with close ties to our growing understanding of the formation of substellar objects under various circumstances.

This particular issue, however, should not be considered exclusively from the point of view of astronomers, because it has the potential for interfering with concepts that have become deeply rooted in the public over several thousand years and thus may generate much confusion. Any new terminology that we introduce in this area must therefore have strong logical links to common usage and popular culture. *Whatever we do, we must not sow confusion.*

Probably the main public perception of a planet is that *"planets orbit stars."* For the public this appears to be a far more important distinction than absence of nuclear burning. It follows that the concept of giant planets should be restricted to objects that are *in orbit*, and should not be used for free-floaters.

Ideally, we would want an operational definition that can ultimately be based on observations, not on properties like origin, which in many cases will be utterly impossible to determine with any certainty.

My personal preference would be to drop the (after all rather meaningless) term "brown dwarf," and call all free-floating substellar objects *"substars"* (some of which can be binaries). All substellar objects in orbit around a star should instead be called giant planets. (If such giant planets are found to have objects orbiting around them, these should be called moons.) This preserves the ancient distinction between planets and stars and, moreover, it is easy to use.

What is unsatisfactory about this is that two objects with the same mass and internal structure would be in different categories, depending on whether they orbit a star or not. But we are in a similarly unsatisfactory situation if we arbitrarily define giant planets to be objects beneath the deuterium-burning limit, as seems to become increasingly common, because there is no real difference between two objects straddling the deuterium-burning limit. Any definition we choose will force some objects that are essentially similar to be artificially separated. This is because there is a continuity between the masses of stars and planets. Only the ancient definition that planets wander around a star, while stars are free-floating objects, offers a sharp distinction.

7. Hans Zinnecker

I have no strong opinions on the terminology of a "planet," but (unlike the IAU Working Group) I am inclined to give weight to the formation process in a circumstellar disk, not just some limit on the mass. This seems to be important when it comes to judge whether free-floating planetary mass objects are planets or not. Although it may not be easy to decide the origin of free-floating planetary mass objects, it should be admitted that these low-mass objects can be "planets" that were ejected from circumstellar disks by gravitational perturbations, in particular in binary systems (Zinnecker 2001). They need not have formed directly through cloud fragmentation like stars. Perhaps the question of their origin (ejection or not) can be examined by kinematic studies, measuring their proper motion in young clusters, for example, by future astrometric/interferometric observations (Zinnecker & McCaughrean 2001).

Of course, the other big issue is how and where to draw the line between giant exo-planets and brown dwarfs in orbit around a single star. My suggestion here would be to discriminate between two types of *systems:* call it a planetary system if the low-mass object in orbit (like Jupiter) is accompanied by other even lower-mass objects (like Saturn, Neptune, etc.), but call it a binary system (with a brown dwarf secondary) if the low-mass object is the sole companion in orbit. Another definition which I like has already been suggested here by T. Mazeh and is based on the existence of the "brown dwarf desert" around G-stars, indicating a useful discrimination between brown dwarfs and planets in terms of two different formation processes.

Finally, if we knew for sure that Jupiter-like planets could not form directly by gravitational instability of a circumstellar disk, but only through gas accretion onto a rocky core, the conceptual discrimination would be obvious: brown dwarfs are those objects that form by gravitational instability (either in a massive circumstellar disk or in a cloud core) and planets are those objects that form during the evolution of an axisymmetric gas and dust disk, where grains grow to planetesimals, and Jupiter-like planets ultimately form from disk gas accretion onto the most massive solid bodies (several earth masses). In this case, all giant exo-planets will have a solid inner core, while brown dwarfs will not. Spectroscopic measurements of chemical anomalies may be able to detect the difference between planetary mass objects with and without a rocky core.

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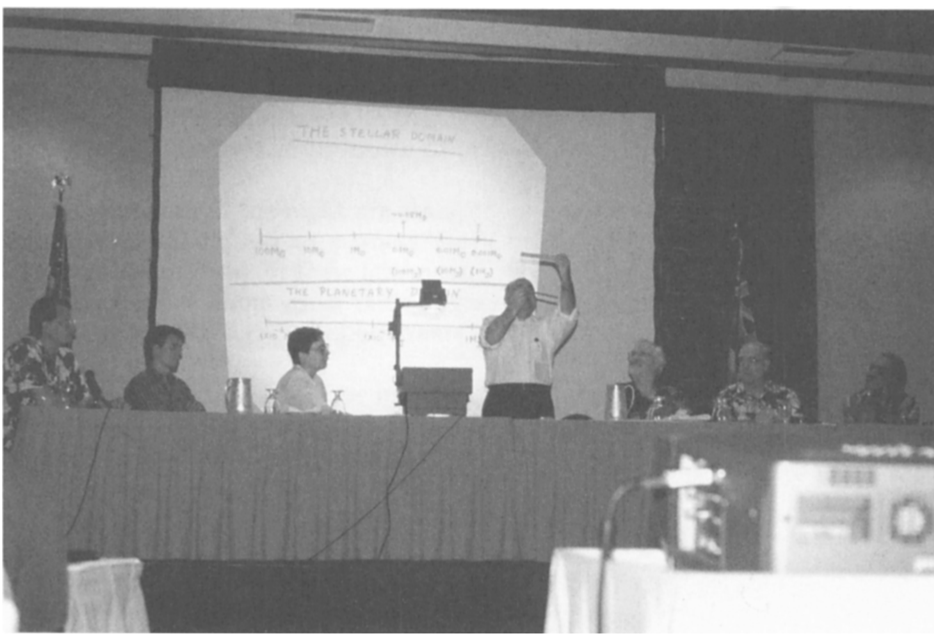

Shiv Kumar explains his vision to the panelists and the audience.

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