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Short communication

On the low-mass planethood criterion

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Abstract

We propose a quantitative concept for the lower planetary boundary, requiring that a planet must keep its atmosphere in vacuum. The solution-set framework of Pečnik and Wuchterl [2005. Giant planet formation. A first classification of isothermal protoplanetary equilibria. Astron. Astrophys. 440, 1183–1194] enabled a clear and quantitative criterion for the discrimination of a planet and a minor body. Using a simple isothermal core-envelope model, we apply the proposed planetary criterion to the large bodies in the Solar System.

Keywords: Solar system-planets; Exoplanets; Definition

1. Introduction

The number of known planets has increased by more than an order of magnitude within the last decade—for the current list of extrasolar planets see e.g. Schneider (2005b). Those additional planets created a diversity which made the task of defining *what is a planet* all the more difficult. Three distinct groups of properties are relevant when discussing the planethood criteria: physical characteristics, planetary dynamics, and cosmogony (for discussion see e.g. Basri, 2003).

1.1. Orbital dynamics

While the majority of the community agrees that dynamically dominant bodies bound to stars or stellar remnants should be counted as planets (provided that they're not massive enough to support fusion), presently there's no consensus on how to designate potential unbound planetary-mass objects. Disagreement partly stems from a lack of understanding of the formation process(es) that could create unbound planetary-mass objects. The current guideline of the International Astronomical Union's (IAU) Working Group on Extrasolar Planets (WGESP, 2005) classifies such bodies not as 'planets', but as 'sub-brown dwarfs'.

1.2. Cosmogony

The present knowledge on the cosmogony of planets in general (e.g. Wuchterl et al., 2000 for an overview) is far from being complete. On the other hand, for a foreseable time there will be no way to observationally infer the history of exoplanets in detail. It is difficult to use cosmogony for any general planethood criterion which would be determinable from easily observed characteristics (e.g. Basri, 2003; Stern and Levinson, 2000). Hence, WGESP guideline (WGESP, 2005) does not include cosmogony in the planet definition.

1.3. Physical properties

The 'planetary mass' has its upper boundary around $13\,M_{♃}$ ($M_{♃}$ being Jupiter mass) as a deuterium burning limit (e.g. WGESP, 2005; Basri, 2003; Stern and Levinson, 2000), but also as an effective upper end of the extrasolar planet mass-distribution (Marcy and Butler, 2000; Schneider, 2005a). The observational limit suggests that $13\ M_{♃}$

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effective boundary is a consequence of an as-of-yet not fully understood formation process, and that the deuterium burning limit is either a side effect or a numerical coincidence. The emerging 1 $M_{♃}$ characteristic mass (Schneider, 2005a) also questions the importance of the thermonuclear reactions as the planetary delimiter. We should note that the recent trend of discovering Neptune-class planets (e.g. Butler et al., 2004; Bonfils et al., 2005) could further reduce the observed characteristic mass.

Various concepts have been proposed for the lower planetary mass limit, but the official consensus is not yet reached. Concepts are based either on a particular physical property of the body in question, or on setting the arbitrary value for the required mass or radius of the body. An arbitrary boundary is based either on a historical heritage (e.g. discovery of Pluto) or on some numerical peculiarity of the Solar System (e.g. size of Ceres). In the past decade, the diversity of members of planetary family has been shown to grossly exceed examples from the Solar System. Hence, we feel that the general definition of a planet cannot include arbitrary values introduced from our own planetary neighborhood.

Continuing on the physical concepts for the low-mass planetary boundary, a few similar ideas are based on roundness of the body, i.e. a body must be massive enough for its self-gravity to dominate over any material forces that might produce asymmetric shapes (e.g. Basri, 2003; Stern and Levinson, 2000). The minimum size of such body somewhat depends on its composition, but one can calculate it to be a bit less than 500 km in diameter (Basri, 2003). However, much smaller bodies can also achieve round shape via melting, or other form of asteroid differentiation; for review see McCoy et al. (2005), Taylor et al. (1993). McCoy et al. (2005) denoted that already a 10 km iron meteorite could reach 90% partial melting early in the formation process, and 'given that iron meteorite parent bodies were in the range of 10–100 km in radius, high degrees of partial melting must have been reasonably widespread, given the abundance of iron meteorite groups and ungrouped meteorites.' Additionally, from the round shape of km-sized rubble pile asteroids (e.g. Dactyl, moon of Ida, c.f. Davis et al., 1996) we know that roundness can be acquired via violent kinetic events.

These facts hint that 'roundness' could be connected to the cosmogony of the object rather than to its physical properties only, and as such would not be an ideally suited observable. Hence, roundness is not a proper concept at the bottom of the planetary mass scale.

The presence of other physical properties, such as a magnetic field, an atmosphere, or the existence of a satellite, has been proposed as the planethood criterion. Stern and Levinson (2000) show that any single such criterion is unable even to include all of the Solar System planets.

While the concept for the lower planetary mass limit is not yet a big problem for the extrasolar-planet surveys, it is the subject of a heated debate concerning the Solar System: Pluto's double classification (both as a minor planet and a planet) and the upcoming issue of what to do with its potentially even larger cousins from the trans-Neptunian-object family (e.g. Brown et al., 2005). It has been suggested (e.g. Marcy and Butler, 2000)—completely arbitrary and mostly for historic reasons—to accept Pluto's mass as the lower mass delimiter. Others have argued the same for the mass of Ceres (e.g. Basri, 2003). IAU has no official position yet, with WGESP opting for 'the minimum mass/size required for an extrasolar object to be considered a planet should be the same as that used in our Solar System.'

In the next section we present our version of the low-mass planetary boundary. The third section summarizes the model of Pečnik and Wuchterl (2005), which we use in the fourth section to apply our planethood criterion to the large bodies in the Solar System. The last section summarizes the paper with conclusions and remarks.

2. Low-mass planetary boundary

During the course of our investigation, we have developed a concept for a global static critical core mass (Pečnik and Wuchterl (2005), to which we refer further on as Paper I). We make use of this concept to provide a planethood criterion to discriminate a planet from a lesser body (e.g. an asteroid). Alternatively, it could be a boundary between a 'major' and a 'minor' planet. The following discourse should be valid in addition to fulfilling the dynamical planethood criteria, i.e. being the gravitationally dominant body in an orbit around a star or a stellar remnant.

As previously stated, the upper mass limit for a giant planet has to be below the limiting mass for thermonuclear fusion of deuterium (WGESP, 2005). The lower mass limit for a giant planet is often assumed without much deliberation, but could be stated as: 'An object is a giant planet if it is able to keep its atmosphere, composed mainly from the solar-composition gas of the parent body, against the surrounding vacuum.'

In the absence of the well-quantifiable physical property which would distinguish a rock (minor planet) from a (terrestrial) planet, we propose to apply the planethood criterion valid for giant planets also to the terrestrials. Previous similar concepts required a body to have an atmosphere. This was unsatisfactory because this requirement excluded atmosphereless planets (e.g. Mercury), *and* had a difficulty in setting the limit between an 'atmosphere' and a 'vacuum'.

We argue that an object should not be called a *planet* if it is not *capable* to retain its envelope (volatiles) when connected to vacuum (i.e. to an empty space, as opposed to the proto-planetary nebula gas cloud). We do not require an atmosphere, just the capability to retain it. The survey of the hydrostatic proto-planetary core-envelope systems (Paper I) describes the envelope properties,