Changes in a scientific concept: what is a planet?

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Abstract

The need for an explicit and exact definition of a planet has arise out of the growing rate of discovery of Trans-Neptunian Objects (TNOs) with physical and orbital properties comparable with those of Pluto, the smallest planet of the solar system. On July 29, 2005, the IAU Circular 8577 has announced the discovery of a TNO, named 2003UB313, bigger than Pluto; its discoverers have asserted that 2003UB313 must be regarded as the tenth planet of the solar system. Lacking of a definition of a planet, the International Astronomical Union has been unable to decide whether 2003UB313 should be classified as a planet, and no official name has been given to 2003UB313. Eventually, astronomers gathered at the 26th General Assembly of International Astronomical Union agreed on a definition of a planet, and Pluto was demoted from the role of planet. This situation is very interesting for the philosopher of science who can be an eyewitness of a real process of explication of a scientific concept. In this paper I examine various proposals for defining the concept of a planet and put them into a philosophical context. The principal philosophical results is that planet, as defined by the new official definition, is not a natural kind.

1. The need for a definition of a planet

The need for a definition of a planet has arisen out of the growing rate of discovery of Trans-Neptunian Objects (TNOs) with physical and orbital properties comparable with those of Pluto, the smallest planet of the solar system. Some astronomers have proposed to consider a few number of TNOs as planets, thus increasing the number of planets of the solar system from nine to an unknown number probably less than twenty-five (Basri [1999, 2003]). Another group of astronomers has proposed to change the status of Pluto, demoting it from planet to the first discovered TNO, thus decreasing the number of planets to eight (Brown [2004]). A third group has suggested for Pluto a dual status as a major and a minor body (Marsden [1999], A'Hearn [2001]). On July 29, 2005, the IAU Circular 8577 has announced the discovery of a TNO, named 2003UB313, larger than Pluto[1]; its discoverers have asserted that 2003UB313 must be regarded as a planet, the tenth planet of the solar system (Brown [2005]). Lacking of a definition of a planet, the IAU has been unable to decide whether 2003UB313 should be classified as a planet, and no official

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[1] Its estimated size is about 3.000 km (Bertoldi et al. 2006); Pluto's diameter is about 2.300 km.

name has been given to 2003UB313. The discovery of 2003UB313 has precipitated the need for a definition of a planet.

The International Astronomical Union (IAU)[2] has established the Working Group Definition of a Planet under Division III - Planetary System Sciences in order to consider the definition of a minimum size for a Planet. The Working Group has completed the assigned task – without reaching general consensus – and has sent a report to the IAU Executive Committee. Later IAU has established the Planet Definition Committee in order to "resolve the issue in a manner that had a solid scientific basis and which might achieve consensus" (Williams [2006]). Eventually the Planet Definition Committee has proposed a definition of planet with a draft resolution (IAU [2006a]) which has been voted in the IAU General Assembly in Prague, August 2006. The passed resolution (IAU [2006c]) was indeed different from the proposed one.

2. The discovery of asteroids and of Pluto

The ancient Greek astronomers identified seven celestial bodies that appear to move with respect to the fixed stars. They named them planets, from the Greek word πλανήτης, *planetes*, which means wanderer. The seven planets were the Sun, the Moon, Mercury, Venus, Mars, Jupiter and Saturn. With the Copernican revolution the Earth substituted the Sun as a planet. The discovery of Jupiter's Galilean moons produced a new category of celestial objects: the satellites of the planets. The Moon was reclassified and demoted from the role of planet.

We are particularly interested in the history of the discovery of Ceres (and later of the other asteroids) and in the discovery of Pluto (and later of the other TNOs). In 1766 the German astronomer, physicist and biologist Johann Daniel Titius noted that the distance of the planets from the Sun, measured in Astronomical Units[3] (AU), can be approximately expressed by a suitable formula, later popularized by the German astronomer Johann Elert Bode; the formula is now known as Titius-Bode's law. The discovery of Uranus in 1781 (by German-born British astronomer Wilhelm Friedrich Herschel), with the semi-major axis closes to the predicted value, gave a strong support to Titius-Bode's law. The law predicted the existence of an unknown planet at about 2.8 AU from the Sun. In 1799 a group of twenty-four astronomers organized by Hungarian astronomer Franz Xaver von Zach decided to undertake a systematic search for a missing planet between Mars

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[2] The International Astronomical Union (IAU) was founded in 1919, in order to promote astronomy through international cooperation. The IAU is the internationally recognized authority for naming celestial bodies. It is organized (October 2005) in 12 scientific divisions, 37 commissions and about 90 working groups.

[3] An Astronomical Unit is the length of the semi-major axis of the Earth's orbit around the Sun (about 150 million kilometers).

and Jupiter. On January 1, 1801, Italian astronomer Giuseppe Piazzi (who did not take part to the search) discovered by accident Ceres. Its distance from the Sun was very close to the value predicted by Titius-Bode's law, and thus Ceres was immediately regarded as the missing planet. In 1802 the German physician and astronomer Heinrich Wilhelm Matthäus Olbers discovered another object, Pallas, at 2.8 AU from the Sun. In 1804 the German astronomer Karl Ludwig Harding discovered a third object, Juno, at 2.7 AU. In 1807 Olbers discovered a fourth object, Vesta, at 2.4 AU. Olbers proposed a theory according to which those celestial bodies were fragments of a disintegrated planet. Herschel, the discoverer of Uranus, coined the name asteroids to refer to them, from a Greek word meaning *star-like* (due to the small dimensions of asteroids, in the telescopic view they appear as points without a discernible disk, such as stars). Ceres, Pallas, Juno and Vesta were regarded as planets until the half of the nineteenth century[4]. The demotion from planets began with the discovery of other objects orbiting between Mars and Jupiter: the fifth asteroid was discovered in 1845, and by the end of 1851 fifteen asteroids were known. At this point there were three main reactions. First, the special symbols previously used for referring to asteroids were abandoned and the asteroids were named by a number in the chronological order of discovery. Second, the asteroids were listed in ephemerides in a dedicated section separated from the planetary section. Third, the name 'minor planets' was coined. Finally, the estimated size for Ceres, Pallas and Juno, which was excessive, suddenly dropped to a too small value.[5]

What is the philosophical lesson from this story? A supposed natural law predicts the existence of a planet at a distance of 2.8 AU from the Sun. An object is found at 2.8 AU from the Sun. This discovery is regarded as a confirmation of the law, and thus the object is regarded as the searched planet. When other objects are found at the same distance from the Sun, they are regarded as the remnants of a destroyed planet. When too many objects are found, a new class of celestial objects is created (asteroids), and the discovered objects are demoted from planets. We can view this story as a brilliant example of a self-correction procedure in science, operating according to a logical and rational scientific attitude: in a first moment, observations seemed to agree with an alleged scientific law; later observations proved that the agreement with the law was only apparent, and a new category of objects is created to account for the new discoveries.

The discovery of Pluto is, in the essential points, almost identical to Ceres' discovery. Early in the twentieth century U.S. astronomers Lowell and Pickering, studying alleged perturbations of

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[4] Ceres, Pallas, Juno and Vesta were listed as planets in introductory texts; in published ephemerides they were listed between Mars and Jupiter, in the section dedicated to planets; special symbols were invented for denoting them, as usual for the other planets.

[5] As an example, the estimated size for Pallas was about 3.380 km in 1850, and only 270 in 1856; now its estimated size is about 500 km (see Hughes [1994]).

Uranus' orbit, predicted the existence of a Trans-Neptunian planet. U.S. astronomer Tombaugh, in 1930, after a systematic search, found a new object, Pluto, at about six degree from the predicted position. Pluto was immediately recognized as the ninth planet of the solar system. However, its size, estimated from the apparent magnitude, was lesser than the predicted size; also its estimated mass was too small in order to account for Uranus' perturbations. Only in 1978, with the discovery of Pluto's moon Charon, it was possible to determine the mass of Pluto with great precision: Pluto's mass was too small and not in agreement with predictions. It became evident that the discovery of Pluto, near the predicted position, was only an accident. Starting with 1990s many objects were discovered after Neptune's orbit, and they were called Trans-Neptunian Objects (TNOs). Several objects have a mass comparable to that of Pluto, and an object (2003UB313) has an estimated mass greater than Pluto's mass. Eventually a question about Pluto's status as a planet was proposed.

3. Some proposals for defining a planet

The definition of a planet that the IAU is searching can be viewed as a test between different conceptions of science: the decision about Pluto's status can be guided by logical principles or by historical considerations; astronomers can consider only empirical evidence or they can consider tradition. The problem facing astronomers is very interesting for the philosopher of science who has the opportunity to be an eyewitness of a real process about a difficult decision, which can be motivated by empirical evidence or by history and tradition. Now I will examine the principal definitions which have been proposed.

The first definition I examine is proposed by Gibor Basri, Professor of Astronomy at the University of California at Berkeley. Basri [2003] suggests that there are three different kinds of properties pertinent to the definition of a planet. First, there are the *characteristics*, which are the physical attributes such as mass, size, luminosity; second, there are the *circumstances*, the most important of which are the orbital attributes; third, there is the *cosmogony*, which is the way of formation. The main characteristic on which the discussion is focused is the maximum and minimum mass of a planet. The maximum mass can be determined in two different ways: one can consider the mass above which core fusion is possible, or one can consider the mass above which electron degeneracy is possible. The former sets a limit of about 13 Jupiter masses, the latter sets a limit of about 2 Jupiter masses. Thus the upper mass for a planet is between 2 and 13 Jupiter masses. The lower mass can be determined by the requirement that a planet has a spherical shape: it is below Ceres's mass, and corresponds to a size of about 500 km for an object with a density similar to the asteroids. These considerations suggest two definitions:

A *fusor* is an object capable of core fusion, that it is an object with a mass above 13 Jupiter masses.

A *planemo* (short for 'planetary-mass object') is a spherical non fusor, that it is an object with a mass between Ceres's mass and 13 Jupiter masses.

With respect to the circumstances, there are two main questions, one whether an object not orbiting around a star can be regarded as a planet, the other about the orbital dominance of a candidate planet. The first question is important because astronomers have discovered planetary-mass objects not orbiting around a star, but free-floating in star clusters. Basri suggests that the requirement that a planet must orbit around a star is essential for the definition of a planet. The second question is strictly involved with the status of the largest asteroids and with Pluto's status as a planet. The largest asteroids where demoted from planets because too many objects were found near them. On the contrary, the nine recognized planets (with Pluto's exception) have removed other comparable objects from their orbit. Pluto is too small to achieve this result, and it is accompanied by several objects with similar mass and orbit. In this respect, Pluto and Ceres are indistinguishable. For historical reasons, Basri is prone to retain Pluto as a planet, and thus he does not consider that the orbital dominance requirement is essential.

Basri suggests that the cosmogony of planets is too uncertain to be useful in a durable and effective definition. Thus he puts forward the following definition:

A planet is a planemo orbiting a fusor.

According to this definition, not only Pluto retains his status as a planet, but also the largest asteroids regain their status as planets. Moreover, the largest TNOs discovered must be regarded as planets.

Mike Brown, a member of the group which discovered 2003UB313, has analyzed four criteria for a definition of a planet (Brown [2004]). The first criterion is a purely historical one: the known nine planets are the only planets in the solar system and nothing else is a planet. Brown discarded this definition, because it "makes the word 'planet' meaningless as a scientific definition" (Brown [2004]). The second criterion is a slight variation of the first: the nine known planets are planets and every object larger than Pluto is also a planet. Brown discarded this definition because there is no scientific reason to set the boundary at Pluto's size. The third criterion regards as a planet every object "*which is round due to its gravitational pull and which directly orbits the sun*" (Brown [2004], italics in the original). Here the problem is – according to Brown – that this definition is historically incorrect. In the history of astronomy there is no reference to the roundness of a body as a condition for its status as a planet. For example, Ceres was initially considered a planet, and later demoted from planet, but its shape was unknown. The fourth criterion is orbital dominance. All known planets, with the exception of Pluto, are solitary objects, that is "in their region of space there is only them […] and then a collection of much much smaller objects […] with no continuous population in between" (Brown [2004]). On the contrary, Ceres, Pallas, Juno and Vesta are not solitary objects "because one region of space contains objects with a continuous range of sizes" (Brown [2004]). Brown accepted this criterion as a definition of a planet: a planet is a solitary object in the solar system. According to this definition, Pluto is not a planet, for the very same reason according to which Ceres is not a planet: they share their orbit with similar objects. This definition excludes 2003UB313 – at that time yet unknown – from the list of planets.

After the discovery of 2003UB313, Brown has changed his mind and has suggested a different definition (Brown [2005]). The most important point, according to Brown, is culture. "Pluto is a planet because culture says it is" (Brown [2005]). From this assumption, Brown easily shows that the only rational choice is to regard as a planet every object bigger than Pluto. Thus 2003UB313 is a planet, the tenth planet of the solar system. Brown plainly admits that this definition is very different from the definition he proposed one year before.

The Working Group on Extrasolar Planets (WGESP) under Division III – Planetary System Sciences of the IAU has proposed a working definition of a planet in extrasolar systems. The need for such a definition has arisen out of the discoveries of planets in extrasolar systems. Due to the limitations in the sensibility of the observational techniques, the discovered planets typically have a mass greater than Jupiter, the most massive planet of the solar system. Thus a question has arisen about the value of the mass above which a celestial body cannot be considered a planet. Moreover, free-floating objects (i.e. objects not orbiting around a star) have been discovered in star clusters: are they planets? The definition of a planet developed by WGESP is aimed to answer such questions. WGESP has proposed a working definition of a planet, "subject to change as we learn more about the census of low-mass companions" (WGESP [2001]). A planet is an object with a mass below 13 Jupiter masses (the limiting mass for core fusion) that orbits a star. The lower mass for a planet should be the same as that used in our solar system (thus nothing is said about the status of Pluto and Ceres). Really, the lower mass is now not important in the search for extrasolar planets, because of the limited sensibility of empirical techniques.

According to the draft definition proposed by the IAU Planet Definition Committee (IAU [2006a]) a planet is a celestial body which is round due to its gravity[6], orbits a star, and is not a star nor a satellite. In a binary or multiple system, if the barycentre is inside the primary object, the secondary is called 'satellite'; otherwise, when the barycentre resides in space (i.e. the centre of gravity is outside the primary object) the secondary object is a planet if it satisfies the other conditions. According to this definition, the known planets in the Solar system are twelve: the nine planets actually known (Pluto retains his status as a planet), the larger asteroid Ceres, the recently discovered 2003UB313, and Pluto's larger moon Charon (the barycentre of Pluto-Charon system is outside Pluto, and Charon is massive enough to be round). There are also a dozen of candidate planets (nine TNOs and three asteroids). This definition does not said anything about the upper limit of the mass for a planet, and thus the definition can be applied only to those planetary systems (such as our Solar system) where candidate planets are not too massive.

Finally, the definition passed at the 26th IAU General Assembly held in Prague, August 2006, defines a planet as a celestial body that orbits the Sun, has a round shape due to its gravity[7], and has cleared the neighbourhood around its orbit (IAU [2006c]). According to this definition, Pluto is demoted from planet, and the known planets in the Solar system are eight: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. A category of celestial objects, called "dwarf planet", has been defined. A dwarf planet is a celestial object that satisfies the first two conditions for planets (i.e. orbits the Sun and is round), but has not cleared the neighbourhood around its orbit, and is not a satellite. Examples of dwarf planets are Pluto, Ceres, and 2003UB313. This definition is explicitly aimed to our Solar system, not to extrasolar planets, and thus it does not address the problem of the determination of the upper limit for the mass.

I briefly recapitulate the proposed definitions.

(3.1) A planet is a round object with a mass below 13 Jupiter masses orbiting an object whose mass is above 13 Jupiter masses (Basri [2003])

(3.2) A planet is an object with an orbital dominance (fourth definition examined and accepted in Brown [2004])

(3.3) Pluto is a planet because culture says it is; every object bigger than Pluto is a planet (Brown [2005])

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[6] More precisely the proposed definition says that a planet is a celestial body that has sufficient mass so that it assumes a hydrostatic equilibrium shape.

[7] More precisely the passed definition says that a planet is a celestial body that has sufficient mass so that it assumes a hydrostatic equilibrium shape.

(3.4) A planet is an object with a mass below 13 Jupiter masses that orbits a star; the lower mass for a planet should be the same as that used in our solar system (the working definition proposed by WGESP [2001]).

(3.5) A planet is an object which is round due to its gravitational pull, orbits a star, and is neither a star nor a satellite (the draft definition proposed by the IAU Planet Definition Committee in IAU [2006a]).

(3.6) A planet is an object which is round due to its gravitational pull, orbits the Sun, and has cleared the neighbourhood around its orbit (the definition approved in the 26th IAU General Assemble IAU [2006c]).

4. Different kinds of definitions

It is useful to remember some basic notions of the theory of definition, and confront them with the suggested definitions of a planet. Hempel [1952] recognizes and discusses the following different kinds of definitions: nominal definition, analytic definition, empirical definition and explication.

A nominal definition is a linguistic convention that introduces a new notation (called definiens) for an expression (called definiendum) whose meaning is already known. The definiens is an expression which does not occur in the language before the definition, while the definiendum is an expression with a well defined meaning. The definiens is an abbreviation for the definiendum. The definitions of fusor and planemo are examples of nominal definition. The expression ‘fusor’, the definiens, is introduced as an abbreviation for “an object capable of core fusion”, the definiendum, which already has a definite meaning. After the introduction of fusor, also the expression “a round non-fusor” has a well defined meaning, and ‘planemo’ is an abbreviation for such expression.

An analytic definition deals with the meaning of an already given expression (called analysandum), and it provides an expression (called analysans), which is a synonymous of the analysandum. Both the analysans and the analysandum occur in the language, with a definite meaning, before the definition is formulated. The analytic definition explicates the meaning of the analysandum, and it supplies an expression that is a synonymous of the analysandum. The question whether an analytic definition is true or false can be resolved with the aid of linguistic methods; it is not an empirical question. Is the required definition of a planet an analytic definition? The expression ‘planet’ already occurs in the language of astronomy with a definite meaning, and perhaps the only aim of a definition is to explicate this meaning. If the definition of a planet were an analytic definition then its validity would be ascertained with a linguistic analysis, without the help of factual knowledge. The definition proposed in Brown [2005] is an analytical definition. Brown analyses the historical and cultural meaning of ‘planet’ and concludes that Pluto must be regarded as a planet. This definition is not granted by factual knowledge, but it is a consequence of an analysis of the meaning of ‘planet’ in its everyday usage.

An empirical definition states the necessary and sufficient conditions for a given phenomenon. It is not at all a definition (thus it is more commonly called an empirical analysis) but it is an empirical law. The definition “a fusor is an object whose mass is above 13 Jupiter masses” is an empirical definition. Why is the limiting mass equal to 13 Jupiter masses? Why 13, and not 8 or 100? Because the core fusion is possible only above 13 Jupiter masses. The selected value of the mass is determined by an empirical law. Suppose that more accurate scientific knowledge proves that the core fusion is possible only above 20 Jupiter masses: thus the definition of fusor will be considered inadequate. An empirical definition is true or false, and its status can be determined only by the experience or, more precisely, by the scientific knowledge. Is the required definition of a planet an empirical definition? The answer is no. Many scientific elements take part in a suitable definition of a planet but there are elements that cannot be determined by means of scientific knowledge alone. Apparently there is no scientific criterion according to which one can determine whether Pluto is a planet or not; this is the very difficulty for an acceptable definition.

An explication deals with the meaning of an already given expression (called explicandum), and it provides an expression (called explicans[8]), which explicates, by means of linguistic and empirical methods, the meaning of the explicandum. The explicandum is an expression that occurs in scientific and natural language without a well-defined meaning. The explicandum is used in science, sometimes as a self-evident expression, but really its meaning is not definite. An example (Hempel 1952) is ‘truth’, which was used in natural and scientific language without a definite meaning until Tarski’s formal explication. Is the required definition of a planet an explication? The answer is yes. The word ‘planet’ occurs both in natural and scientific language; its meaning is not well-defined, probably because there was no reason for an explication. Until now, in every circumstance, it was possible to judge whether an object were a planet or not. Also the dispute about Ceres, Juno, Pallas and Vesta was settled without the necessity for an explicit definition of a planet. The discovery of 2003UB313 has now precipitated the need for an explication of the meaning of ‘planet’.

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[8] The term 'explicans' corresponds to the term 'explicatum', which was preferred by Carnap [1950].

5. Requirements for an explication

A problem of explication is, by definition, not well-defined. We cannot decide, in an exact way, whether a proposed explication is correct. “Strictly speaking, the question whether the solution is right or wrong makes no good sense because there is no clear-cut answer” (Carnap [1950], p. 4). A well-known example of an explication is the Church-Turing thesis, which states that every computable function can be computed by a Turing machine. This is an explication of the informal notion of ‘computable function’ by means of the well defined notion of Turing machine. Is the Church-Turing thesis true? The question is undefined, because the expression ‘computable function’ has no definite meaning; in a sense, it is the Church-Turing thesis that gives a well-defined meaning to the notion of ‘computable function’. The problem of a definition of a planet is similar to the Church-Turing thesis. We cannot ask whether a proposed definition is the right one, because the term ‘planet’ has not a precise and stable meaning in scientific language. We are searching for a definition of ‘planet’ because of the lack of definiteness of this notion; thus, we are not in the condition to decide about a proposed definition using empirical, logical and linguistic methods universally accepted. We can try to adopt suitable requirements for an explication, in order to determine the more satisfactory definition. Carnap [1950] discusses four requirements for an explication: similarity to the explicandum, exactness, fruitfulness, and simplicity (p. 5). The last three are the most important, while the first requirement is probably too strong, and it is often not in agreement with the actual scientific procedure.

Exactness means that the definition must be stated in exact terms and must be applicable without uncertainties. Fruitfulness means that the explicans must be useful for the formulation of scientific laws. Simplicity means that the definition must be based on properties that are easily ascertainable.

Now we can try to confront the definitions (3.1) - (3.6) of a planet using these three criteria. In order to examine their simplicity (or complexity) it is important to identify the physical properties that are referenced. Definition (3.1) requires the determination of shape and mass of the candidate planet. Definition (3.2) is based on the orbital dominance, which requires the knowledge of orbit and mass of neighbour objects. Definition (3.3) is based on the size of the candidate planet. Definition (3.4) is based on the mass of the candidate planet. Definition (3.5) requires the knowledge of shape, mass, and possibly the barycentre of a multiple system (thus we must know the mass of the components of the multiple systems, or their orbit). Finally, definition (3.6) is based on shape, mass, and orbital dominance.

The following table shows the physical properties referenced by the definitions.

Definition	Physical properties
3.1	Shape. Mass.
3.2	Orbital dominance (i.e., orbit and mass of neighbour objects).
3.3	Size.
3.4	Mass.
3.5	Shape. Mass. Barycentre of a multiple system (Mass or orbit of the components).
3.6	Shape. Mass. Orbital dominance (i.e., orbit and mass of neighbour objects).

It is easy to order these definitions according to their simplicity. Definitions (3.3) and (3.4) are simpler than the other definitions. Definition (3.5) requires at least the knowledge of the same properties than definition (3.1), and thus definition (3.1) is simpler that definition (3.5). Definitions (3.2) and (3.6) are the most complex, because they require the knowledge of the physical properties not only of the candidate planet, but also of its neighbour objects. Thus, according to their simplicity, the definitions can be ordered in this way[9] : (3.3) =*s* (3.4) >*s* (3.1) >*s* (3.5) >*s* (3.2) >*s* (3.6).

With respect to the criterion of exactness, only definition (3.1) is exact. It explicitly determines the upper limit of the mass of a planet, and implicitly – via the requirement of the roundness – the lower limit. On the contrary, definitions (3.2), (3.3), (3.5), and (3.6) does not define the upper limit of the mass, and definition (3.4) does not define the lower limit of the mass. Thus the definitions can be ordered as[10] (3.1) >*e* (3.2) =*e* (3.3) =*e* (3.4) =*e* (3.5) =*e* (3.6).

What about the fruitfulness of these definitions? The lack of scientific reasons supporting definition (3.3) suggests that probably it cannot be fruitful. This definition uses a constant (Pluto's size) which have no theoretical meaning in astronomy. Look at definition (3.1): it also uses a constant, the 13 Jupiter masses, but this constant has a precise scientific meaning: it is the mass above which core fusion is possible. 13 Jupiter masses is not an empirical constant, but a theoretical one, in the sense that it can be determined by means of theoretical principles and it is connected

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[9] "a =*s* b" means "a and b are equivalent with respect of their relative simplicity", and "a >*s* b" means "a is simpler than b".

[10] "a =*e* b" means "a and b are equivalent with respect of their relative exactness", and "a >*e* b" means "a is more exact than b".

with important principles of physics. On the contrary, the constant used in definition (3.2) (Pluto's size) can be determined only by means of empirical methods and it is not connected with theoretical principles. Thus it seems to be unlike that Pluto's size can occur in useful scientific laws. So we can put definition (3.3) in the last place with respect to the (presumable) fruitfulness. Definition (3.4) cannot solve the current debate over the status of Pluto, Ceres or 2003UB313, because it does not define the lower mass of a planet. However it can be applied in the study of extrasolar planets. Thus it seems that definition (3.4) is slightly more useful than (3.3). What about the other definitions? In first approximation, we can assume that they can be useful in the same way – we have no reason to think otherwise. Thus[11] : (3.1) =*f* (3.2) =*f* (3.5) =*f* (3.6) >*f* (3.4) >*f* (3.3). We have found the following relations:

(3.3) =*s* (3.4) >*s* (3.1) >*s* (3.5) >*s* (3.2) >*s* (3.6)
(3.1) >*e* (3.2) =*e* (3.3) =*e* (3.4) =*e* (3.5) =*e* (3.6)
(3.1) =*f* (3.2) =*f* (3.5) =*f* (3.6) >*f* (3.4) >*f* (3.3)

The six proposed definitions are ordered in different ways according to different criteria. The three criteria here used – simplicity, exactness, and fruitfulness – are *prima facie* equivalent. At a first sight, it seems impossible to order these definitions from the best one to the least suitable. If we try to construct an absolute ordering > from the above relations, we encounter some difficulties. For example, from the first relation we deduce (3.3) > (3.1) > (3.5). But from the third relation (3.5) > (3.4) > (3.3), and we have a contradiction. In this case, however, it is possible to build an absolute ordering in the following way. For every pair of definitions, we count the case in which the first definition precedes the second. For example, definition (3.1) beats definition (3.2) two to zero (definition 3.1 precedes definition 3.2 in simplicity and exactness, and is equivalent in fruitfulness). We have the following results:

(3.1) > (3.2)   (3.1) > (3.3)   (3.1) > (3.4)   (3.1) > (3.5)   (3.1) > (3.6)
(3.2) < (3.5)   (3.2) > (3.6)   (3.3) < (3.4)   (3.5) > (3.6)

Thus we have the following order[12] : (3.1) > (3.5) > (3.2) > (3.4) > (3.3), (3.1) > (3.5) > (3.2) > (3.6); definitions (3.4) and (3.3) cannot be confronted with definition (3.6) – their relative order is not determined.

We can adopt a different analysis for the exactness of the definitions: we can consider a definition exact if the definition is applicable in our Solar system. In this case, we have a different

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[11] "a =*f* b" means "a and b are equivalent with respect of their relative fruitfulness", and "a >*f* b" means "a is more fruitful than b".

[12] "a ~ b" means that the order between a and b is not definite, i.e. that there are no element to determine whether a is better that b or whether b is better that a.

order according to exactness (3.1) =*e* (3.2) =*e* (3.3) =*e* (3.5) =*e* (3.6) >*e* (3.4). The absolute ordering is: (3.1) > (3.5) > (3.2) > (3.6) > (3.4); definitions (3.3) cannot be ordered.

In every case, it seems that definition (3.1) is the best, followed by definitions (3.5) and (3.2).

6. Natural kinds

We can approach the problem of a definition of a planet from a different vantage point, turning our attention to natural kinds. Various conceptions of natural kinds have been proposed, but there is no general agreement about their nature and their role in science. Examples of the disagreement about natural kinds can be found easily, and some of them are briefly illustrated in the following lines. Chemical elements, such as water and gold, are usually considered natural kinds (Putnam [1975], Mellor [1977]); however, Collier [1996] claims that chemical elements are not natural kinds. Biological species are often regarded as natural kinds and sometimes are considered the paradigmatic case of natural kinds (Boyd [1991]) but, according to a strict interpretation of the essentialist view, species are not natural kinds (Hull [1978]). Collier [1996] claims that natural kind terms feature in scientific laws, while Machery [2005] considers this notion too restrictive and proposes to substitute scientific laws with *ceteris paribus* generalizations. According to Quine [1969], a subset of a natural kind usually is a natural kind (in Quine's example, green emeralds are a kind) while, according to Machery [2005], a subset of a natural kind usually is not a natural kind (in Machery's example, the set of white dogs is not a natural kind).

I'll examine the problem of the definition of a planet in the light of the three different approaches distinguished by Machery [2005]. First, the essentialist account (Putnam [1975]): natural kinds are determined by essential intrinsic properties; an entity belongs to a natural kind because it possesses some essential intrinsic properties. Second, according to Collier [1996], natural kinds are those that features in scientific laws, that is in general statements supporting counterfactuals. Third, according to the causal notion of natural kinds (Boyd [1991]), entities belonging to the same natural kind tend to possess similar properties due to a causal mechanism.

First, the essentialist account. A natural kind is determined by some essential intrinsic properties. For example, water is a natural kind because it can be defined in terms of an essential intrinsic properties, that is its chemical formula: water is H_2O. On the contrary, Goodman's grue objects are not a natural kind, because there is no essential intrinsic property that defines grue objects. What about planet? Is planet a natural kind? Is planet definable in terms of essential intrinsic properties? Look at definition (3.3); it requires that a planet must have a size greater than Pluto. With this restriction, a planet cannot be a natural kind, because in the definition there is a not eliminable reference to a specific object. Of course, one can substitute the reference to Pluto with a numerical value and require that a planet must have a size larger than 2300 km (Pluto's diameter). But if someone ask why this numerical value, the only possible answer contain a reference to Pluto. On the contrary, definitions (3.1) and (3.4) define a natural kind, in spite of the reference to Jupiter; in fact, this reference can be eliminated, because the numerical value of the mass is determined by a physical law. So the definitions really refer to a general physical law, not to a specific object. Definition (3.5) makes use of essential intrinsic properties of the candidate planets, such as shape and mass, and possibly the centre of gravity of a multiple system – and the centre of gravity is determined by the mass of the components. Thus definitions (3.1), (3.4) and (3.5) define an object as a planet based on essential intrinsic properties; according the essentialist account, planet is a natural kind. Is the orbital dominance – the properties referenced by definition (3.2) and (3.6) – an essential intrinsic properties? No, because the orbital dominance depends not only from the physical properties of the candidate planet, but mainly from the physical properties of the neighbour celestial objects.

Now the second account of natural kinds: natural kinds are those that appear in scientific laws. Well known laws concerning planets are Kepler laws. Consider the first law: The planets orbit the Sun in elliptical orbits with the Sun at one focus. Now there is a problem: the class of planets is a subset of a larger class about which the same law can be formulated. Not only planets orbit the Sun in elliptical orbits with the Sun at one focus, but also asteroids, satellites, and comets. The same is true for the second and third Kepler law. Kepler laws can be formulated of a larger class than planets. Thus, if we require that a natural kind "is not a subset of a larger class about which the same generalizations could be formulated" (Machery [2005] p. 448), we are forced to conclude that we cannot use Kepler law in order to identify planets as a natural kind.

Finally, the causal notion of natural kinds, according to which entities belonging to the same natural kind tend to possess similar properties due to a causal mechanism. What kind of causal mechanism can be invocated in order to grant similar properties to the planets? Probably only their common origin. However, the cosmogony of planets is too uncertain to be useful in this respect. Thus we are forced to dismiss considerations about the causal notion of natural kinds – not because this account of natural kinds if flawed, but because we lack scientific valuable knowledge about causal mechanisms concerning planets.

Now we can compare the proposed definition with the following general definition of natural kind: “A class C of entities is a natural kind if and only if there is a large set of scientifically relevant properties such that C is the maximal class whose members tend to share these properties because of some causal mechanism” (Machery [2005], pp. 447-448). Are there scientifically relevant properties such that planets tend to share these properties? Yes. For example, planets are cold and dim (they are not star); they can have an atmosphere (planet are round due to their gravitational pull, or have an orbital dominance, and thus can be large enough to maintain an atmosphere); they can have water in the surface (because they are not too hot nor too small); thus they can – at least in principle – sustain life. Are the properties of planets shared because of some causal mechanism? Probably yes, due to their common origin, but the actual knowledge is not enough in order to give an answer. Finally, is the class of planets a subset of a larger class with the same scientifically relevant properties? The answer is yes. Several satellites are spherical due to their gravitational pull, and have enough mass to maintain an atmosphere or water. In Solar system, the physical properties of the largest satellites are similar to the physical properties of the Earth-like planets; really, there is more similarity between Earth-like planets and the largest satellites than between Earth-like planets and giant planets. Thus planet is not a natural kind.

7. Taxonomy and dual classification

The question concerning Pluto's and 2003UB313's status can be viewed as a problem of classification, that is as a problem of taxonomy. The principal role of taxonomy is to provide a natural classification of a determined set of objects. An appropriate taxonomic system is based on observational data; in other words, it is necessary that the characteristics used in order to classify the objects can be empirically verifiable or, at least, can be inferred, in a straightforward way, from other observational properties or quantities. This requirement is, of course, a question of degree: there are properties easily observable (e.g. the apparent magnitude of a star); there are properties which can only be inferred from other observational quantities (e.g. the mass of the components of a binary system); there are properties that, at least in the present stage of scientific knowledge, cannot be deduced from observational data (e.g. the formation processes of the planets). What about the different criteria proposed for a definition of a planet? Mass, size, luminosity, roundness, orbital dominance, and eccentricity, are observational data. They can be determined more or less directly from observations. It is particularly difficult to estimate the mass m of an extrasolar planet, because astronomers can only determine the quantity $m \sin i$, where i is the inclination of the planet’s orbit with respect to the ecliptic; thus *m* sin *i* is the lower limit of the planet's mass. However, an estimation of the mass is simpler for an object in the solar system.

We can turn our attention to biology, where taxonomy is very useful and highly developed. Three points are important in biology: first, classifications are subjected to change; second, taxonomy is often based on evolutionary consideration and, when possible, classifications are based on the phylogenetic tree; third, at least in principle, an organism belongs to one and only one taxon, although several different classifications have been often proposed for the same organism[13].

We can consider these three points with respect to astronomy. Also in astronomy classifications are subjected to change. Thus, the demotion of Pluto from planet, or the promotion of Ceres and 2003UB313 to the status of planet, can be viewed as natural and normal changes in a taxonomic system, suggested by new scientific evidence. With respect to the second point, a classification based on formation processes is not useful in astronomy: due to our ignorance about planetary formation processes, such kind of classification cannot be based on observational data. The third point is very interesting, because in astronomy there are examples of objects with a dual classification. There are celestial bodies belonging to two different classes of objects, which were originally considered distinct and without common members. The best known example is Chiron (see A'Hearn [2001]). Chiron was originally classified as an asteroid; later, when a cometary activity was discovered on Chiron, it was inserted in the catalogue of comets, without removing it from the catalogue of asteroids. Thus Chiron belongs to two different sets of celestial objects (it is an asteroid and a comet); these two sets were mutually exclusive before Chiron re-classification. After the case of Chiron, other objects were classified as comets and asteroids (see A'Hearn [2001]).

Dual classification can suggest relations between two different sets of objects, which were previously unrelated. In the case of Chiron, dual classification as asteroid and comet suggested the hypothesis that near-Earth asteroids may be dormant comets. Marsden [1999] and A'Hearn [2001] propose a dual classification for Pluto: "As with […] Chiron […], where the choice of 'minor planet' or 'comet' designation depends on the context, we are proposing that Pluto would have dual status as a 'major' and a 'minor' body" (Marsden [1999]). An advantage of Pluto's dual classification is that it will expand the sample of icy planets and the sample of TNOs that reached a libration with Neptune (A'Hearn [2001]). Thus dual classification can be very fruitful, in the sense that dual classification is useful for the formulation of scientific laws and hypothesis. With respect to the three requirements for an explication examined in the paragraph 5, dual classification is the

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[13] Taxonomic pluralists argue that there are overlapping classifications, i.e. an organism can belong to different taxa (see Ereshesfki [2001]).

best suited for a definition of a planet. It is simple, because it does not alter the existing criteria; it is formulated in exact terms; and, moreover, it is the most fruitful.

These considerations are very interesting from a philosophical point of view. They remember us that there are many different ways in order to construct a classification, and that there is not an absolutely correct method, but every kind of classification depends on the context. If an astronomer is interested in the study of comets, he can determine certain criteria according to which celestial bodies are classified as comets. With respect to these criteria, Chiron is a comet. If an astronomer is interested in asteroids, she can determine certain criteria according to which celestial bodies are classified as asteroids. With respect to these criteria, Chiron is an asteroid. In the same way, if one is interested in the physics of icy planets, then he can consider Pluto as an icy planet; if one is interested in the dynamics of TNOs, then she can consider Pluto as a TNO. Sharp distinctions are not always possible, and not always they are desirable.

8. Conclusion.

I think that I have showed that some philosophical tools could be of some utility in the debate concerning the definition of a planet. The principal intent of this article was not to suggest a new definition of a planet but to analyze several proposed definitions using a couple of philosophical instrument – the analysis of definition and explication, and the current debate over natural kinds – in order to understand their philosophical implications. The principal philosophical results is that planet, as defined by the new official definition, is not a natural kind.

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