Pluto and the 'Planet Problem': Folk Concepts and Natural Kinds in Astronomy

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The Pluto controversy provides fertile new ground to revisit the traditional philosophical problem of natural kinds and scientific change. Here I show that further insight into the Pluto case is gained by drawing out some of the striking analogies with what is termed the "species problem" in the philosophy of biology. I argue that the taxon 'planet' can still be considered a natural kind term despite the fact that a) its meaning and extension have changed over time, b) there are multiple scientifically compelling definitions of planet, and c) many of those definitions include historical and/or relational properties.

1. Introduction

The 2006 decision by the International Astronomical Union to strip Pluto of its status as a planet generated considerable uproar not only in scientific circles, but among the lay public as well. After all, how can a vote by 424 scientists in a conference room in Prague undermine what every well-educated second grader knows is a scientific fact?

The Pluto controversy provides a new and fertile ground in which to revisit the traditional philosophical problems of natural kinds and scientific change. Before engaging these philosophical problems, however, there are two misguided reactions to the Pluto controversy worth dispelling from the start. The first misguided reaction is that this sort of classificatory about-face is unprecedented in science. To the contrary, many such

This paper was first presented as a talk in the Boston Colloquium for Philosophy of Science in 2008; I am grateful to Richard Boyd and other audience members there for their feedback. I would also like to thank Dr. Arielle Moullet of the National Radio Astronomy Observatory for her help making sure the astronomy details cited in this paper are accurate and up to date. Any remaining errors are, of course, my own.

Perspectives on Science 2014, vol. 22, no. 4

doi:10.1162/POSC_a_00146

reclassifications can be found, for example, in the biological sciences: whales are not fish, koala bears are not bears, and more recently modern birds are actually dinosaurs, hence the dinosaurs did not all go extinct. Indeed, as we shall see later on, this isn't even the first time that the notion of planet has undergone significant revision. Science is in the business of creating taxonomies, and with new scientific discoveries these taxonomies and their extensions can change.

The second misguided reaction to the Pluto controversy is that it is *merely* a matter of semantics. On this view, it is simply a question of how we use words—nothing substantive—let alone scientific—is at stake in the debate. As Shakespeare's Juliet proclaims "What's in a name? That which we call a rose by any other name would smell as sweet." The scientists working in planetary science, however, are at pains to disagree. For example, Alan Stern, who is head of NASA's "New Horizons" Pluto-Kuiper Belt mission, and his colleague Harold Levinson write,

> Classification schemes have played and continue to play a useful role in astronomy because they allow us to put bodies into a structure with recognizable correlations of physical parameters. [. . .] While the discussion that has gone on may at times have centered on semantics, we believe that classification schemes play an important role in the scientific process. (Stern and Levinson 2002, 1)

Taxonomies, when they are done correctly, are not superfluous to science, but rather play an important role in the organization of scientific knowledge, the prediction of new phenomena, and the formulation of scientific explanations. Some taxonomies are clearly better than others, and it should go without saying that not any random collection of objects will be useful for scientific reasoning.

Granting then that taxonomies are important to science, the next question becomes what is it that distinguishes a scientifically useful taxonomy from an unhelpful one? The traditional philosophical answer to this question is that the successful scientific taxonomies are those whose taxons correspond to *natural kinds.* On this view, there are objective groupings of things in the universe into categories, and a natural-kind taxonomy is one that correctly "carves nature at its joints," to use Plato's apt metaphor.[1] As we shall see, however, there is considerable disagreement in the philosophical literature concerning how precisely natural kinds should be understood. On the traditional view, natural kinds are defined by a set of necessary and sufficient properties that are possessed by all and only members of the kind; these properties must be intrinsic (not relational or historical)

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[1] Plato, *Phaedrus* 265d–266a.

and together they define the unchanging essence of the kind.[2] So, for example, the chemical element potassium is taken to be a natural kind whose essence is to have an atomic number of 19 (that is, it has 19 protons in its nucleus). The intrinsic property of having exactly 19 protons in its nucleus is a necessary and sufficient condition for being potassium, and all and only those substances which are potassium have exactly 19 protons.

Following the work of Richard Boyd, however, there has emerged a new conception of natural kinds that is rapidly gaining ground. On this view, a natural kind is defined by what Boyd calls a "homeostatic property cluster" (HPC) (Boyd 1999). HPC natural kinds are defined as a family of properties that are clustered in nature as a result of various underlying homeostatic or causal mechanisms. Unlike the traditional view, these properties need not be intrinsic, but can be relational or historical as well. Furthermore Boyd grants that the extensions of these kinds may have vague boundaries, and this vagueness counts neither against the kindhood nor naturalness of the kind. What is essential is that there be what he calls an 'accommodation' between these HPC kinds and the causal structure of the world; such an accommodation is important because it is what makes successful inductions and scientific explanations regarding these kinds possible.

This philosophical question over how we are to understand natural kinds underlies much of the contemporary debate in astronomy concerning how to define 'planet'. Although astronomers and planetary scientists do not use the language of natural kinds, one of the chief issues dividing the planet debate is between those who think that the term planet should be defined solely in terms of intrinsic properties (such as mass limits), and those who think that historical properties (specifically how the body was formed) and relational properties (whether the body is orbiting a star) are essential to the definition of the kind. As we shall see, there are many striking similarities between the planet debate in astronomy and a longstanding debate in the biology literature concerning how species should be defined, known as the "species problem." By tracing this analogy between the species problem and what I am calling the "planet problem" in some detail, the current controversy over Pluto can be profitably placed into broader philosophical context.

2. An Analogy to the Species Problem

By way of setting up the planet problem let me give a very brief overview of the species problem. To those outside of biology and the philosophy of biology, species would appear as quintessential examples of natural kinds.

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[2] A relational property is a property a thing has in relation to something else, while an

Since the Darwinian revolution, however, the realization that species arise through a complex process of speciation challenges the traditional essentialist view that there is some set of properties that all and only members of given species possess. As Marc Ereshefsky explains,

> A number of forces conspire against the universality and uniqueness of a trait in a species. Suppose a genetically based trait were found in all the members of a species. The forces of mutation, recombination and random drift can cause the disappearance of that trait in a future member of the species. [. . .] Again biological forces work against the uniqueness of a trait within a single species. Organisms in related species inherit similar genes and developmental programs from their common ancestors. [. . .] Another source of similar traits in different species is parallel evolution. Species frequently live in similar habitats with comparable selection pressures. (Ereshefsky 2007, 3)

Not only is it the case that there is rarely a set of unique properties defining a species, but contemporary biologist also deny that species can be uniquely individuated on the basis of their genetic material. It turns out that variability in DNA is often *not* a good indicator of morphological variability nor of reproductive compatibility (Brookes 1998, 3). A striking example of this is the fact that there is a greater genetic difference between sibling species of drosophila fruit fly than there is between humans and chimpanzees (King and Wilson 1975). Despite the intuitions of many philosophers, it does not appear that the essences of species are to be found in their "microstructure."[3]

The "species problem" refers to the fact that there is no single agreed-upon way to define biological species. A 1997 book by Michael Claridge and collaborators surveyed more than a dozen different ways in which biological species can be defined, each with its own scientific merits and limitations. The most well-known perhaps is Ernst Mayr's Biological Species Concept (BSC), which defines species in terms of reproductive compatibility and an ability to produce fertile offspring. Problems with the BSC definition of species include that it does not work for species that reproduce asexually, it is inapplicable to paleospecies, reproductive isolation

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intrinsic property is a property a thing has in itself. So, for example, I have the relational property of being a mother, but the intrinsic property of being brown eyed.

[3] This "microstructure" view of essences has been endorse at various points by philosophers ranging from John Locke to Saul Kripke and Hilary Putnam; see Bird and Tobin (2008) for a review.

occurs gradually making for vague boundaries, and hybrids—which are quite common in the plant world—are often not weak or sterile.

Philip Kitcher (1984) has noted that one can distinguish two broad "families" of approaches to defining species. The first approach emphasizes morphology or structural similarities as being of paramount importance, while the second approach emphasizes phylogenetic relationships—that is, history and genealogy override similarity. In this latter category is included cladistics, which defines species as comprising a common ancestor and all its descendents. Advantages of the morphological approach (also sometimes referred to as the classical or Linnean approach to species) include that it is based on intrinsic and observable properties, while the disadvantages include that is not based on our current theoretical understanding of how species arise, it admits of vague boundaries, and has difficulties handling things such as sexual dimorphism (that is, females of different species may be more structurally similar to each other than they are to the males of their own species). Phylogenetic approaches, on the other hand, emphasize relational properties such as having a common ancestor.

In an influential series of articles from the 1970s the biologist Michael Ghiselin (1974) and the philosopher of biology David Hull (1978) argued that species should not be thought of as natural kinds, classes, or universals at all; rather they should be thought of metaphysically as individuals.[4] What is relevant here is not their positive argument that species should be conceived of as individuals, but rather their negative arguments that species are not the sort of thing that can be properly thought of as kinds. Specifically one can find the following four reasons cited for why species are not kinds. First, attempts to define species in terms of some fixed set of intrinsic properties fail. Second, species have vague boundaries; that is, there are borderline cases where it seems no amount of information would settle whether a particular organism or set of organisms does or does not belong to the species. Third, species membership is spatio-temporally restricted: species not only come into existence and go extinct, but they are importantly *historical* entities, whose member organisms are connected by a particular pattern of descent. To borrow an example from Joseph LaPorte, even if one were to find on Alpha Centauri an animal that is genetically and morphological indistinguishable from horses here on earth, they would still not be horses because they do not share the same

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[4] Species are individuals in the sense of having proper names, not having defining properties (intensions), there cannot be instances of them, and their constituent organisms are parts not members (Ghiselin 1974, 536).

evolutionary history (Laporte 2004; see Hull 1978, 349 for a similar example). This is in contrast with "proper" natural kinds, such as iron, that are spatio-temporally *unrestricted*—any atom in the universe found to have 26 protons would count as iron. A fourth reason cited for why species cannot be kinds is that species *evolve* whereas abstract kinds cannot (see Ghiselin 1987, 129; Ghiselin 1981, 303; and Laporte 2004, 9–10 for a discussion).

More recently a number of philosophers, such as LaPorte (2004), Boyd (1999), and Paul Griffiths (1999), have countered these objections, arguing that they are not in fact obstacles to viewing biological species as natural kinds. Before examining the responses to these objections, however, let us turn to the planet problem, where we will see that these same four objections can be leveled against planet being considered a natural kind as well. The striking points of analogy between the 'species problem' and the 'planet problem' are summarized in Figure 1 below.[5] Although there is no simple solution to the species problem that we can import to solve the planet problem, the value of drawing out this analogy is three-fold. First, just as it was helpful for biologists and philosophers of biology to be able to recognize, label, and explicitly discuss the species problem, it is similarly helpful for those interested astronomy and planetary science to have an explicit framing of the planet problem. Second, debates in the astronomy literature, about whether historical and relational properties are admissible in the definition of astronomical kinds, would be advanced by recognizing that historical and relational properties have figured prominently in the definitions of kinds in other sciences, such as biology. Third, it is important for philosophers of science more generally to see that the species problem may not in fact be an anomaly in science, but rather part of a larger pattern that is more common, especially in what is termed the "historical sciences."

3. The Planet Problem

One can find almost as many competing definitions of planet in the astronomy literature as one can find definitions of species in the biology literature. Most of these definitions for planet can be grouped into one of the following two families of approaches: The first group consists of those

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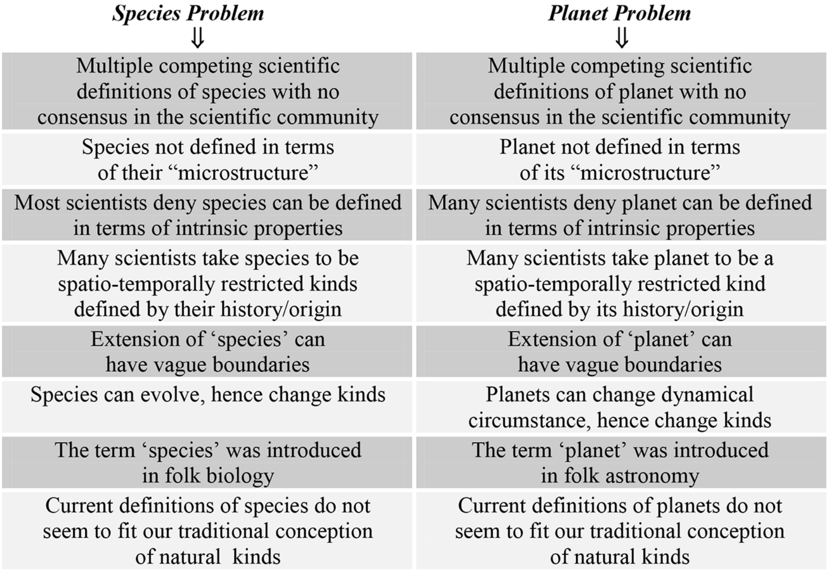
[5] One point of disanalogy between the species problem and the planet problem is that one can distinguish the species category in general from specific species taxa (such as felis catus), the latter of which consists of the concrete entities, whereas in the case of the taxon 'planet' the members are the concrete entities themselves (although there are planets with different characteristics, they are not recognized as constituting their own taxanomic categories or subkinds in the same way.)



Species Problem ⇓	*Planet Problem* ⇓
Multiple competing scientific definitions of species with no consensus in the scientific community	Multiple competing scientific definitions of planet with no consensus in the scientific community
Species not defined in terms of their "microstructure"	Planet not defined in terms of its "microstructure"
Most scientists deny species can be defined in terms of intrinsic properties	Many scientists deny planet can be defined in terms of intrinsic properties
Many scientists take species to be spatio-temporally restricted kinds defined by their history/origin	Many scientists take planet to be a spatio-temporally restricted kind defined by its history/origin
Extension of 'species' can have vague boundaries	Extension of 'planet' can have vague boundaries
Species can evolve, hence change kinds	Planets can change dynamical circumstance, hence change kinds
The term 'species' was introduced in folk biology	The term 'planet' was introduced in folk astronomy
Current definitions of species do not seem to fit our traditional conception of natural kinds	Current definitions of planets do not seem to fit our traditional conception of natural kinds

Figure 1. Analogies between the "Species Problem" and the "Planet Problem." Should we conclude that 'species' and 'planet' are not natural kind terms?

who think planet should be defined solely in terms of intrinsic properties, while the second group emphasizes historical and relational properties, such as how the body was formed and whether it has dynamically dominated the other bodies in its orbit. While the first approach tends to be favored by planetary geologists (more generally referred to as planetary scientists), the second approach is favored by a group of astronomers generally referred to as dynamicists.

It is interesting that one of the few points of agreement between these different groups is that the interior structure and composition of a planet is irrelevant to the definition of its kind. In our own solar system, for example, the composition of the planets varies significantly. There are the four "terrestrial" or "rocky planets": Mercury, Venus, Earth, and Mars, which are made of heavy elements with iron cores; then there are the two "gas giants," Jupiter and Saturn, which are largely made of hydrogen and helium; finally, there are the two "ice giants," Uranus and Neptune, which are composed primarily of water, ammonia, and methane ices, with considerably less hydrogen and helium gases than the other giant planets. Other likely intrinsic properties such as having an atmosphere or having a magnetic field also fail to capture planethood, for example ruling out Mercury and Venus respectively.

Those who want to define planet in terms of intrinsic properties tend to focus either on the shape of the object or on specific mass limits. The original definition of planet proposed by the International Astronomical Union on August 16, 2006—a proposal that was later voted down and replaced on August 24—focused on the object's shape, specifically whether the force of gravity of the body exceeds its material strength, forcing it to take a spherical shape. The proposal specifically defined planet as follows:

> A planet is a celestial body that (a) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (b) is in orbit around a star, and is neither a star nor a satellite of a planet. (http://www.astronomy2006.com/press-release-16-8-2006-nine.php)

In addition to being an intrinsic and easily observable property, an advantage of this definition is that the threshold at which an object becomes round is scientifically important insofar as it marks the transition between an object that is geophysically dead to one that is active, having convection occur in its interior (Basri and Brown 2006, 198). Although the shape of a body is correlated with its mass, it is not identical to a mass-based definition of planet insofar as the mass at which an object become round varies with the substance of the body; for example, icy bodies can reach hydrostatic equilibrium at much smaller masses than rocky bodies.

If this definition of planet had been adopted then not only would Pluto still be considered a planet, but three more planets would have been added to our solar system as well: Ceres, which is traditionally thought of as an asteroid,[6] Charon, which is traditionally thought of as a moon of Pluto, and Eris, a trans-Neptunian object in the scattered disk.[7] A number of objections have been raised against this definition of planet, however. First, a qualitative characteristic such as roundness forms a continuum, and hence is vague with borderline cases. As one astrophysicist criticized, "[D]oes gravity dominate the shape of a body if the cross-section deviates from hydrostatic equilibrium by 10% or by 1%? Nature provides no unoccupied gap between spheroidal and nonspheroidal shapes, so any boundary would be an arbitrary choice" (Soter 2006, 2513). Another objection to defining

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[6] Ironically, when Ceres was first discovered in 1801 it was believed to be a planet—the eighth planet—however, it was soon realized that it was part of a vast population of rocks that came to be known as the asteroid belt.

[7] "Trans-Neptunian object" (TNO) is a general term used to refer to any object in our solar system that orbits the sun at a distance greater than Neptune. It is divided into two regions: the Kuiper Belt and, at the outer limit of the solar system, the Oort Cloud. There is a third class of TNOs called the "Scattered Disk," which consists of highly inclined or eccentric orbits that can be, at various times, in different regions.

a planet in terms of roundness was raised by Mike Brown, the Caltech astronomer who was involved in the discovery of Sedna and Eris. Although the International Astronomical Union claimed this definition would recognize only 12 planets, Brown argued that there were in fact 53 *known* celestial bodies that would satisfy this definition, with likely over a hundred more to be discovered as astronomers continue to survey the Kuiper belt, leading to almost 200 hundred planets in our solar system alone.[8] This definition, which Brown informally referred to as the "leave-no-ice-ball-behind proposal," was on his view too permissive in admitting members to the kind.

A similar definition of planet based on intrinsic properties is in terms of upper and lower mass limits. This approach has been defended by Stern and Levison who define a planet as

> [A]ny body in space that satisfies the following testable upper and lower bound criteria on its mass: [. . .] the body must: (1) Be low enough in mass that *at no time* (past or present) can it generate energy in its interior due to any self-sustaining nuclear fusion chain reaction (else it would be a *brown dwarf* or a *star*). And also, (2) Be large enough that its shape becomes determined primarily by gravity [. . .]. (Stern and Levison 2002, 4).

Although Stern and Levison formulate their definition in terms of mass limits, they still rely on the hydrostatic equilibrium ("round shape") condition to define the lower mass bound. The difficulty, as was noted before, is that the roundness condition is not in fact equivalent to a mass limit, since it is a function of the density and compressive strength of the particular material. What sets this definition apart from the previous definition is that it does not include what is known as the "circumstance" condition, namely that a planet must be a body orbiting a star. Any body sufficiently massive to be round and less massive than a star counts as a planet—no matter where in the universe that body is.

By focusing on intrinsic properties alone, Stern and Levison have managed to define the kind planet in a spatiotemporally unrestricted way, however this leads to a number of counterintuitive consequences. Not only does this definition admit the 100 or so objects recognized by the previous definition of planet, but it admits at least 100 more, including, for example, the Earth's moon, and at least six other moons in our solar system. Ironically our moon, which had long ago been considered a planet (along with the Sun) on the geocentric Ptolemaic system, would—on this

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[8] Mike Brown (n.d.) *The Eight Planets.* http://web.gps.caltech.edu/~mbrown/eightplanets/.

definition—once again be considered a planet (though of course without the geocentrism). For many, however, any definition of planet that classifies a moon as a planet fails as an adequate definition.

In formulating their definition of planet Stern and Levison first outline a set of desiderata that they believe any definition for planet should satisfy (Stern and Levison 2002, 3). What is particularly interesting about their list of desiderata is that it is largely in accord with a very traditional view of natural kinds. First, they argue that an adequate definition of planet should be physically based, "providing insight into the nature of what planetary bodies are at their essence" (Stern and Levison 2002, 4). Second, it should be based on observable *intrinsic* properties, rather than relational or historical properties (these latter sorts of properties are known in the astronomy literature as "circumstance" and "cosmogony" respectively); third it should be quantitative—that is, numerically based; fourth it should uniquely classify any given body—no body should belong to more than one astronomical kind unless one is a subkind of the other (in the natural kinds literature this is known as a prohibition on cross-cutting categories); and fifth it should not allow a body to change its status as a function of time (Stern and Levison 2002, 3).[9] To this list we can add that the kind planet should be spatiotemporally unrestricted—a planet should be a planet no matter where it came from or where in the universe it is found.

The approach to defining planet exemplified by Stern and Levison is in sharp contrast to the other broad family of approaches for which the historical origin of the body (known as cosmogony) and its dynamical circumstance are considered more important than any particular set of intrinsic properties. One prominent approach in this category defines a planet simply on the basis of the physics of planetary formation. Steven Soter, of the Astrophysics Department at the American Museum of Natural History, for example, defines planet as *the end product of secondary accretion from a disk around a star or substar (aka brown dwarf).* This well-accepted model of planet formation is essentially a refinement of the nebular hypothesis, first proposed by Immanuel Kant in 1755.[10] An interstellar cloud of gas and dust initially collapses under gravitational attraction to form a star. Because the nebula is rotating the remaining gas and dust form a flat pancake-like disk rotating around the star. Accretion is the process by which these small particles collide and stick together forming a number of small planetismals; the gravitational force of the larger

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[9] They identify two further desiderata, namely that it should be robust to new discoveries, and should be simple, comprising the fewest possible criteria (Stern and Levison 2002, 3).

[10] See Kant's "Universal Natural History and Theory of Heaven" (1755), especially Part Two, Section One.

planetismals is then able to draw other smaller planetismals to it eventually becoming large enough to form a planet. The larger a planetismal gets, the more quickly and effectively it can gather even more material to it through gravitational attraction. As Soter describes, the "tendency of disk evolution in a mature system [is] to produce a smaller number of relatively large bodies (planets) in nonintersecting or resonant orbits, which prevents collisions between them" (Soter 2006, 2513). He goes on to explain that "planets, defined in this way, are few in number because the solar system provides insufficient dynamical room for many" (Soter 2006, 2514). This distinguishes planets from smaller objects such as asteroids, comets, and Kuiper belt objects, which have not been able to clear other planetismals from their orbital zones, and hence can continue to collide with other objects.

The historical or "cosmogony" criterion for planethood, based on how the object was formed, incorporates two other popular criteria for planethood based on circumstance. The first circumstantial criterion is whether the body has cleared residual planetismals from its neighborhood either through accretion or scattering, and the second circumstantial criterion is whether the body is orbiting a star. Although these two circumstantial criteria fall naturally out of the cosmogonist's historical definition of planet, they can be embraced independently of it. An advantage of the dynamical clearing of planetismals criterion—whether as a part of the historical criterion or independent of it—is that nature does provide a significant gap between those bodies that can and cannot clear their orbital zone. Soter defines a parameter, μ, which he calls the planetary discriminant; it is defined as the ratio of the mass of a body under consideration to the aggregate mass of all the other bodies that share its orbital zone (Soter 2006, 2514–15). He uses this parameter as a quantitative test for whether or not a particular body is the end product of disk accretion. Surveying the major bodies in our solar system, he notes that there is an unoccupied gap of four orders of magnitude between Mars, which has a μ-value of 5,100 and the closest contender Ceres, which has μ-value of .33. Having an unoccupied gap of 4 orders of magnitude suggest that the division is not an arbitrary or vague one, as in the case of specific mass limits, but rather a division drawn by nature. The implications of this approach are that there are only the eight traditional planets in our solar system—Pluto with a μ-value of .07 does not make the cut. Unlike the mass-limits approach based on round shape, a potato-shaped body on Soter's definition would count as a planet as long as it had cleared its orbital zone. Similarly a very massive body (comparable to Mercury, for example) if discovered in the Oort cloud, would *not* count as a planet on this definition, since it

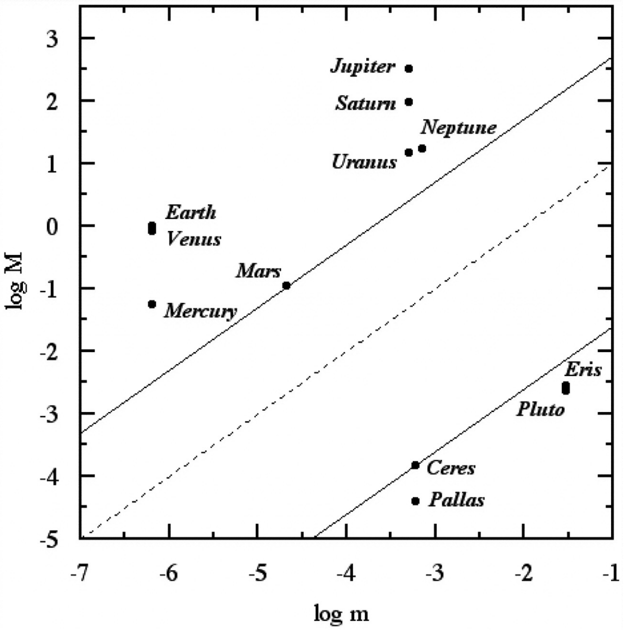

Figure 2. Mass, *M,* of a body versus the aggregate mass, *m,* in that body's orbital zone (in units of Earth masses). The solid lines bound the gap in the ratio of $\mu = M/m$, which is a gap of 4 orders of magnitude between the values for Mars and Ceres. Note that according to this dynamical quantity, Pluto clearly belongs in a different category than the other planets. (From Soter 2006, Fig. 3)

would not be the end product of secondary disk accretion, having cleared its orbital zone.

Soter's definition can also be applied to exoplanets—that is planets outside of our solar system. Focusing on dynamical criteria, Soter argues that to be counted as a proper planet, an exoplanet should have non-overlapping orbits with the other planets in its solar system, or be shielded from collisions by a mean motion resonance. Of all the known multiple-planet exosystems, all but three have non-overlapping orbits, and those three seem to all have a 2:1 mean motion resonance that would prevent them from colliding with their neighbors. Soter concludes "All known exoplanets of main-sequence stars fall well above the gap [. . .][defined by the planetary discriminant μ] and would be classified as planets by the criterion of dynamical dominance" (Soter 2006, 2518).

There has been some debate in the literature over whether the proper characterization of this circumstantial criterion for planethood is in terms of having "cleared planetismals" or "gravitationally dominating" its orbital zone. For example, it has been objected that Jupiter shares its orbit with the Trojan asteroids, and so has not cleared its orbital zone, and hence would seem to be disqualified as a planet on this definition.[11] Advocates of this interpretation respond that clearing planetismals refers only to the period during the formation of the planet—not to objects that later strayed into the planet's path. Furthermore Jupiter clearly dominates the dynamics of the Trojan asteroids, and although the Earth hasn't "cleared" the moon, it gravitationally dominates it as well.[12] By contrast, Pluto does not dominate the other Kuiper belt objects in its orbital zone, Ceres does not dominate the asteroid belt, nor does Eris gravitationally dominate the scattered disk. There is a clear dynamical difference between these two groups of objects: that is, the traditional eight planets on one hand and Pluto, Ceres, and Eris on the other hand. Soter's characterization of planet in terms of his quantitative planetary discriminant parameter μ is able to side step these debates by showing that what might appear to be borderline cases on the clearing account are not in fact borderline at all, when the right dynamical quantity is considered.

The most common objection to using circumstantial dynamical criteria to define planet, such as whether it has cleared planetismals or whether it orbits a star, is that these are highly contingent relational properties, rather than intrinsic properties of the body itself. For example, as Mike Brown and Gibor Basri point out "the terrestrial planets would not have been as effective in clearing planetismals without the influence of [the much more massive] Jupiter" (Basri and Brown 2006, 202). One can imagine two identical bodies, one of which gets classified as a planet because it keeps company with other massive planets that help it clear planetismals from its orbital zone, while its twin, which happens not to share such prodigious company, fails to meet this criterion for planethood. In response to this objection Soter asks, "[W]hy is dynamical context any less relevant [than intrinsic properties]? We refer to objects that orbit planets as 'moons' even though two of them are larger than the planet Mercury" (Soter 2006, 2518). In other words, there is some precedent in astronomy for making dynamical circumstance essential to the definition of a kind.

A related objection to these sort of definitions is that the dynamical circumstance of a body can change. Some stellar systems might be unstable

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[11] Alan Stern quoted in Rincon, P. (August 25th, 2006), *Pluto Vote 'Hijacked' in Revolt,* BBC News. http://news.bbc.co.uk/2/hi/science/nature/5283956.stm.

[12] Brown, Mike (n.d.) *The Eight Planets.* http://web.gps.caltech.edu/~mbrown/eightplanets/.

due to the mutual gravitational influence of very massive planets on each other, which can lead to a planet being ejected from the stellar system. Are these ejected planets still planets? Can a body change the natural kind it belongs to as a function of time?[13] In many ways this is an analog of the objection that, because species can evolve from one kind into another, they cannot properly be considered natural kinds. In the context of the species problem, Ghiselin for example writes: "If species were not individuals, they could not evolve" (Ghiselin 1987, 129). The intuition behind this objection is that natural kinds are abstract objects with immutable essences, hence cannot change. As Laporte rightly responds, however, "when we say 'Species evolve', we do not mean that any abstract kind evolves; [rather] we mean that successive *members* of a kind gradually become different from their ancestors" (LaPorte 2004, 9).

In the case of planets we do not have successive members of a kind, each individual of which belongs to a single kind throughout its existence. Rather, we have a single individual that changes the kind it belongs to as a function of time. Nonetheless, when astronomers assert that a particular planet has been ejected and is no longer a 'planet' but rather what is currently called a 'free-floating object of planetary mass', what they are asserting is not that one abstract object has turned into another abstract object, only that one concrete entity has changed such that it is now an instance of a different kind than it was initially. A completely analogous situation can occur for chemical elements, which are paradigmatic natural kinds. For example, an isotope of potassium known as potassium-40 (with 19 protons) is naturally unstable and can transmutate into an atom of argon (argon-40) by having one of its protons convert into a neutron via positron emission or electron capture; alternatively that same atom of potassium can also naturally transmutate into an atom of calcium (Ca-40) by having one of its neutrons convert into a proton via beta-ray (high speed electron) emission. In this situation we do not say that the abstract kind 'potassium' changed into another abstract kind 'calcium', but rather that a particular atom that was an instance of the natural kind potassium is now, through the afore-mentioned physical process, an instance of the natural kind calcium. To require of a natural kind that instances of its kind cannot change in this respect, is simply too strict of a requirement for natural kindhood given the sort of world we live in. Even if we accept that the ability to change kinds is not an obstacle to the natural kind status of 'planet', there remain several other objections that need to be considered.

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[13] Stéphanie Ruphy (2010) in her excellent article, "Are Stellar Kinds Natural Kinds?" refers to this problem as "taxonomic nomadism."

4. Is 'Planet' a Vestige of Folk Astronomy or a Natural Kind?

Faced with the plurality of competing definitions for planet in the astronomy literature—each with its own weaknesses as well as strengths—one might be easily be led to the view that planet is not in fact a natural kind term at all, and should simply be eliminated from modern astronomy. There are three general worries that can be raised against planet as a natural kind term that seem to speak in favor of this approach. The first is that the term 'planet' was not introduced in the context of a mature scientific theory, but rather was introduced in the vernacular, long before the structure of the solar system and the nature of the bodies it contains was understood. Moreover, both the definition and recognized extension of this term have changed many times throughout history.[14]

Our word 'planet' comes from the ancient Greek word (planaytess) πλανητες meaning the "wandering stars," since the points of light corresponding to the planets seem to move against the background of the other fixed stars. It originally referred to the five planets visible to the naked eye, which are Mercury, Venus, Mars, Jupiter, Saturn. In the Ptolemaic geocentric model, 'planet' meant those bodies that orbit the Earth, which included both the sun and moon as planets, making for a total of seven. With Galileo's discovery in 1610 of the four moons of Jupiter, which he named the Medicean stars, the number of planets grew to eleven (moons and planets were not clearly distinguished at this time). With the eventual acceptance of the Copernican heliocentric model of our solar system the Earth for the first time came to be counted among the planets. By the end of 1684, five satellites of Saturn were discovered, making for sixteen planets. It was only in the 18th century that the term 'moon' became clearly distinguished from planet, and the number of planets dropped back down to six. In 1781 William Herschel discovered Uranus, the seventh planet. Twenty years later (1801) Giuseppe Piazzi discovered Ceres right where the now-discredited Titius-Bode law predicted a new planet should be found. This was quickly followed by the discovery of Pallas, Vesta and Juno, which, according to the best astronomy textbooks of the early nineteenth century brought the number of planets back up to eleven.[15] Early on Herschel had suggested that a new term 'asteroid' be introduced to describe Ceres and its cohorts, but it was only after the discovery of another asteroid, Astrae, and the thirteenth planet, Neptune, which was discovered in 1846, that Herschel's distinction between asteroids and planets took hold, and the number of planets dropped back down to eight. In 1930, Clyde Tombaugh discovered Pluto, which became officially known

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[14] A very readable history of the planets can be found in Weintraub (2007).

[15] For a fuller discussion see, for example, Weintraub (2007), chapter 7.

as the ninth planet. All seemed well with the solar system until, in 2003, Brown and collaborators discovered Sedna, a trans-Neptunian object that is believed to be located in the Oort cloud, which marks the very outer region of our solar system. Although some heralded Sedna as the tenth planet, the issue was really brought to a head in 2005 with Brown's discovery of Eris, a body which is 27% more massive than Pluto.[16] Eris is a "scattered disk" object, which is a dynamical class of objects that are believed to have been scattered from the Kuiper belt, where Pluto lies, and now have highly eccentric orbits.[17] As a body thought to be larger than Pluto, it became difficult to deny that Eris should be counted among the planets if Pluto is. This brings us finally back to the 2006 decision of the International Astronomical Union to demote Pluto, reducing the number of planets in our solar system back down to eight. An abbreviated timeline of the changing conception of planet can be found in Figure 3. As this very brief history shows, both our understanding of the meaning and the extension of 'planet' has undergone significant changes. For many this suggests that 'planet' is not in fact a natural kind term, but only a vestige of folk astronomy. The solution to the planet problem on this view is simply to eliminate this folk concept from modern astronomy.

While some may take the fact that the meaning and extension of a term has changed over time as an indication that it is not a natural kind, I think it suggests just the opposite. If we understand natural kinds as those taxonomies that carve nature at its joints, then as scientists learn more about the structure of the world, we would expect the definitions and extensions of our natural kind terms to be responsive to these new scientific discoveries and insights. It is simply asking too much for our natural kind terms to be immune to scientific progress. Indeed the fact that the term 'planet' has persisted through revolutionary changes in astronomy seems instead

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[16] Although astronomers are confident that Eris is 27–28% more massive than Pluto, it is surprisingly difficult to determine which one is *larger.* Initial measurements with the Hubble telescope in 2006 suggested that Eris was significantly larger than Pluto; however, more accurate occultation measurements (timing Eris's passage in front of a star) indicate that its size is 2326 km across with an uncertainty of +/- 12 km (Sicardy et al. 2011, 138). This means it is approximately the same size as Pluto, which is thought to be 2306 km with an uncertainty of +/- 20 km. The difficulty in determining Pluto's size is complicated by the discovery in the mid-1980s that it has an atmosphere with a thick haze that makes it appear larger. For a discussion see Brown's http://www.mikebrownsplanets.com/2010/11/how-big-is-pluto-anyway.html

[17] Eris is inclined 44 degrees to the ecliptic where the planets are. Scattered disk objects are defined dynamically by their eccentric orbits, rather than as a region of space, since objects like Eris travel from the outer-most regions of our solar system (where it is currently) to distances closer to the sun than Pluto.

Time Period	*Extension term 'Planet'*	*Planet Count*
Ancient Greece	'Wandering stars' visible to naked eye (Mercury, Venus, Mars, Jupiter, Saturn)	5
Ptolemaic geocentric model	Naked eye planets, Sun, and Moon	7
1610	+ 4 moons of Jupiter (Medicean stars)	11
Copernican heliocentric model (post 1543)	- Sun demoted + Earth promoted	11
By 1684	+ 5 moons of Saturn	16
18th century on	Moons distinguished from planets (- 10 moons)	6
1781	+ Uranus	7
1801 – c. 1845	+ Ceres, Pallas, Vesta, Juno	11
1846	+ Astrae & Neptune	13
1846 on	Asteroids distinguished from planets (-5 asteroids)	8
1930	+ Pluto	9
2003	Sedna	10 ???
2005	Eris	11+ ???
2006	IAU decision to demote Pluto and not promote Eris, etc.	8

Figure 3. Abbreviated timeline of the changing conception of 'planet'.

to be evidence that it is a natural kind term in the way that other scientific terms such as aether, phlogiston, and caloric are not.

There are two additional worries that speak against planet as a natural kind term. The second worry is that the proposed definitions of planet do not seem to fit our traditional philosophical conception of what a natural kind term should be like. Traditionally it is thought that natural kinds should be specifiable solely in terms of *intrinsic* properties, which determine the necessary and sufficient conditions for being a member of the kind. On this traditional view, natural kinds should not admit of vague boundaries, nor should they be spatio-temporally restricted—anything with the relevant intrinsic properties should count as a member of the kind no matter where it is or where it came from. Although Stern and Levison's proposed definition was formulated in terms of intrinsic properties—mass limits—it failed to yield a categorically distinct kind in so far as the mass limits admitted vague boundaries; in other words, on this definition any sharp distinction between planet and nonplanet must be arbitrary since there exists a continuum of masses in nature. The alternative definitions for planet, such as the one proposed by Soter, do yield a categorically distinct kind without vague boundaries, but do so only by defining planet in terms of historical and relational properties, such as how the body was initially formed and whether it is orbiting a star. Not only do such kinds fail to be specified in terms of intrinsic properties, but they also yield kinds that are spatio-temporally restricted. To someone wedded to the traditional conception of natural kinds, this would once again suggest that 'planet' is not a natural kind term.

As we saw earlier, these same objections have been raised in the philosophy of biology literature against species being counted as natural kinds. The best current scientific definitions for species are also specified in terms of relational rather than intrinsic properties, admit of vague boundaries, and are spatio-temporally restricted. In response to this, many contemporary philosophers of science, such Richard Boyd, Paul Griffiths, and Joseph LaPorte, have argued that the problem is not with these definitions of species, but rather with the traditional conception of natural kinds. Griffiths, for example, cogently argues that there is no reason why there cannot be kinds with *historical* essences. He writes, "kinds are defined by the processes that generate their instances, and for many domains of objects, these processes are extrinsic rather than intrinsic to the instances of the kind" (Griffiths 1999, 219). More generally, Boyd has offered a new theory of natural kinds in terms of what he calls homeostatic property clusters. On Boyd's conception, natural kinds are defined by a cluster of properties none of which may be necessary or sufficient for membership in the kind. The co-occurrence of the properties in the cluster is brought about by homeostatic mechanisms, that is, some properties tend to bring about the existence of the other properties or there are underlying causal mechanisms which tend to bring about the co-occurrence of these properties.[18] These property clusters can include relational and historical properties and the kind term defined by these clusters may have vague extensions. Important to all these thinkers is the view, emphasized early on by Quine (1969), that the naturalness of the kind is determined by the extent to which reference to that kind plays a central role in successful inductions and scientific explanations.

Applying this approach to the debate over the definition of planet, we see that many of the objections to the recently proposed definitions of planet can be dismissed as being motivated by an outdated and misguided conception of natural kinds. With this new conception of natural kinds, there is no a priori philosophical reason to reject these definitions based on historical properties, such as how the planet was formed, or relational properties, such as whether the body is orbiting a star or has cleared its orbital zone of planetismals. Consider, for example, Soter's definition of planet (as the end product of secondary accretion from a disk around a

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[18] For a clear discussion of the nature of HPC kinds, see Boyd (1999), 143–44.

star): it relies precisely on the sort of underlying "homeostatic" mechanisms that Boyd's HPC account describes, namely that the mechanisms of disk evolution tend to produce a small number of relatively large bodies in nonintersecting orbits. It is these mechanisms, related to the historical origin of the object, that give rise to the property cluster in the definition of planet and that also make this definition of planet so useful for prediction and explanation. Hence, definitions for planet that make use of such criteria are candidates for being natural kinds in Boyd's sense.

The important question, on this new conception of natural kinds, is not whether these definitions of planet are specified in terms of unchanging intrinsic properties, but rather, whether these definitions are facilitating successful scientific predictions and explanations. In other words, insofar as these definitions are scientifically fruitful then they can be legitimately counted as defining *natural* kinds. As Boyd has stressed, "[t]he question of just which properties and mechanisms belong in the definition of [the kind] is an a posteriori question—often a difficult theoretical one" (Boyd 1999, 143). Hence, on this view, whether planet is a natural kind is largely an empirical question to be decided by astronomers.

Even if one accepts that neither the checkered history of the term 'planet' nor worries stemming from the traditional philosophical conception of natural kinds poses any real obstacle to the natural kindhood of planet, there still remains the objection that there is simply no scientific consensus on *which* definition of planet is the appropriate one. Just as in the case of species, there seems to be a plurality of competing definitions for planet each with some claim to legitimacy. In light of this plurality of scientific definitions, I think there are three options available to those who want to defend the natural kind status of planet.[19] The first option would be to defend some version of what might, in analogy with the species problem, be called "planet monism." One could defend monism either by declaring one of these definitions of planet to be the correct one, and dismissing the others as incorrect, or by arguing that there is one correct definition for planet, but that definition has simply not been discovered

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[19] In his recent book *Scientific Enquiry and Natural Kinds* P. D. Magnus devotes a section to the Pluto case and also comes to the conclusion that planet meets the criteria for natural kindhood. His discussion focuses on the IAU definition (not the competing definitions for planet in different accommodation contexts) and the objections he discusses are also different (e.g., the objection that 'planet' is dispensable because a narrower kind such as 'gas giant planet' and 'rocky planet' would do the same work, and the objection that there might be criteria that preserve the traditional nine planets). He also does not draw out the detailed analogy with the species problem; hence, his discussion his complementary to the one I offer here.

yet. The difficulty with monism, however, is that many of these definitions have compelling scientific considerations in their favor, and any attempt to pick one would seem to be arbitrary.

A second approach to defending the kindhood of planet would be to adopt what might be called "planet pluralism." According to the pluralist, there are multiple, equally legitimate definitions for planet, each of which makes some contribution to the prediction and explanation of some domain of scientific phenomena. So, for example, planetary geologists might adopt the definition of planet in terms of mass limits based on hydrostatic equilibrium and nuclear fusion because they are interested in the explanation and prediction of phenomena for which these sort of properties are the most relevant. While, on the other hand, the dynamicists are typically interested in the prediction and explanation of different sorts of phenomena for which dynamical history and the circumstance of the body are more important. Both sets of properties correspond to real and important features of the world, they just differ in their relative importance depending on what explanatory scientific project one is engaged in. To use Boyd's terminology, each subfield of astronomy places different accommodation demands on the classificatory practices they deploy, and while this might appear on the face of it to lead to some form of relativism, it does not, since all the properties appealed to on these various definitions are real and objective features of the world. The central challenge for pluralism, however, is that if there are multiple equally legitimate definitions for planet—each of which may vary in its extension—then is there anything that legitimately unites these various definitions into the kind *planet?*

There is a third approach to defending the natural kind status of planet, and that is in terms of what might be called "planet integrationism." This approach defines planet as the conjunction of two or more different definitions of planet. Integrationism is actually a form of monism in that it argues that there is one correct definition for planet, but takes from pluralism the insight that each of these definitions is latching on to some real, scientifically important feature of the world. As the conjunction of various conditions, planet integrationism tends to be the most stringent approach to defining planet, typically admitting a smaller number of members to its kind than either definition would individually.

Interestingly it was the integrationist approach to defining planet that was finally adopted by the International Astronomical Union on August 24, 2006. According to the 2006 resolution of the IAU, planet is now defined as follows: "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,

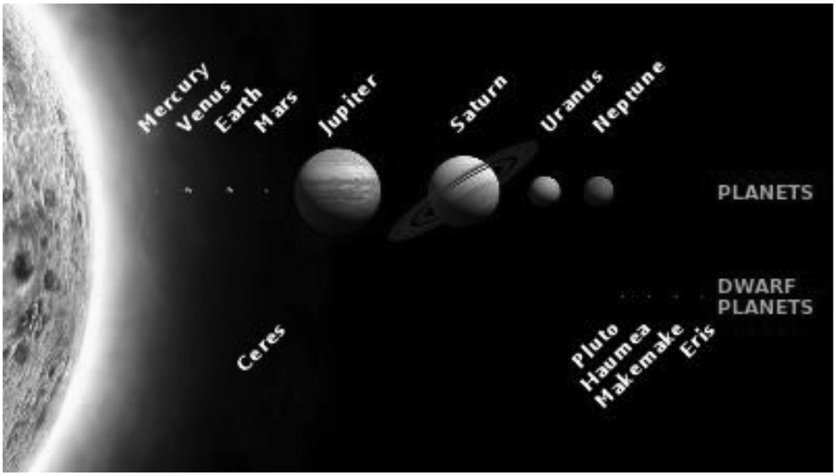

Figure 4. The current understanding of our solar system (as of 2013) is that it consists of 8 planets and 5 dwarf planets (the latter of which include former-planet Pluto and former-asteroid Ceres). Image source: Wikimedia Commons (http://en.wikipedia.org/wiki/File:Solar_System_size_to_scale.svg) public domain.

and (c) has cleared the neighbourhood around its orbit" (http://www.iau.org/iau0603.414.0.html). In this definition we see the integration of three different possible definitions for planet—first, the circumstantial criterion that a planet must be in orbit around the Sun, second the planetary geologist's criterion based on mass limits, which was advocated by Stern and Levison, and third the dynamicist's condition that a planet must have cleared its orbital zone of planetismals, as advocated by Soter. The IAU decided that any celestial body that meets the first two conditions—but not the third—be labelled a "dwarf planet." Hence, although Pluto is in orbit around the Sun and is sufficiently massive to have reach hydrostatic equilibrium, it has not cleared the many neighbouring Kuiper belt objects in its orbit, and so is not a planet, but rather is a dwarf planet (ironically dwarf planets are not a subspecies of planets on this definition). According to this definition there are only eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. For a picture of our current understanding of the solar system see Figure 4.

Although this may sound like a peaceful resolution to a long-standing debate, in so far as this definition requires that a planet be in orbit around the *Sun*—rather than any star or substar—this definition, strictly speaking, only applies to planets in our solar system. As for the over 800 extrasolar planets discovered since 1990, there is still no official definition of planet. It is possible that the issue of how to define planet in a way that includes exoplanets will need to be revisited at a future IAU meeting.

Having examined the tumultuous history of the concept of 'planet,' we are now in a better position to understand the decision to demote Pluto more specifically.

5. Was it *Discovered* that Pluto Is Not a Planet?

The problem at the heart of the Pluto controversy is that the traditional definition of planet, which had been left rather vague, was—in light of new astronomical discoveries—ceasing to be a scientifically *useful* concept. That is, the collection of objects gathered under the previous definition of planet no longer seemed to constitute a natural group, either admitting too many or too few objects, in what increasingly seemed to scientists to be an arbitrary and haphazard way. While it is clear that there had been a growing state of crisis in the field of astronomy over the concept of a planet, what is less clear is whether scientists *discovered* that Pluto is not a planet. In raising this question I am not questioning astronomers' decision to demote Pluto, but rather asking how we, as philosophers of science, should classify this decision: Was it a scientific discovery or a conventional stipulation?

On the one hand, the fact that Pluto's demotion was decided by means of a majority vote by 400-some scientists at a conference in Prague seems to speak in favor of it being merely a stipulation—not a discovery.[20] On the other hand, if it was merely a matter of convention, why was there a scientific crisis at all? I want to argue that this dichotomy is a false one—the decision to demote Pluto involved *both* discovery *and* stipulation. Although there is no one discovery that forced astronomers to conclude that Pluto is not a planet, there were a number of discoveries that were directly relevant and precipitated this decision.

The first important cluster of discoveries has to do with Pluto's mass. At the beginning of the twentieth century Percival Lowell had predicted the existence of a new planet X based on perturbations in the orbit of Uranus and Neptune. Based on these calculations it was determined that the hypothesized planet must have a mass ten times that of Earth. Ironically it was Clyde Tombaugh working at Lowell's observatory, looking in the region of space where planet X was supposed to be, that led to the discovery of Pluto. It slowly became apparent, however, that Pluto was not the planet they had thought it to be: not only was Pluto's orbit inclined 17.1°

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[20] Only 400 of the approximately 10,000 professional astronomers worldwide voted on the resolution, which was not passed unanimously, but only by a majority.

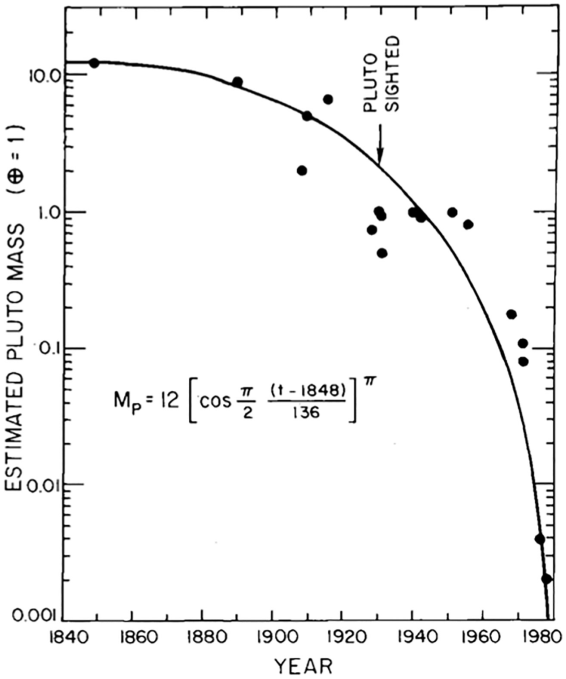

Figure 5. Estimated mass of Pluto (in units of Earth masses) as a function of time (from Dessler and Russell 1980).

to the ecliptic (while the next nearest inclined orbit is only 7° for Mercury), but it was also realized that the mass of Pluto must be closer to *one* Earth mass rather than ten. As this graph from an 1980 article by Alex Dessler and Chris Russell shows, the estimated mass of Pluto has dropped steadily every decade since its discovery.[21] In 1978, when Pluto's moon Charon was discovered, it was determined that Pluto's mass could be no more than .002 times the mass of the Earth. Dessler and Russell jokingly subtitled their paper in which this graph appears "The Pending Disappearance of Pluto."

Not only is Pluto smaller than seven moons in our solar system (including the Earth's moon), but beginning in 1992, it was discovered that Pluto is not an isolated body but rather belongs to a vast collection of objects that make up the Kuiper belt, which includes an estimated 100,000

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[21] Note that the mass of Pluto is not actually changing—only scientists' calculation of the mass of Pluto.

objects all over 100 kilometers in size.[22] The discovery of the Kuiper belt—a region of our solar system beyond the orbit of Neptune—drastically changed scientists' perception of Pluto, making it an object much more analogous to Ceres in the asteroid belt (as we saw in the previous section, Ceres was also demoted from being a planet in the mid-1800s when the many other objects in the asteroid belt were discovered).

Since the 1990s astronomers have not only discovered the Kuiper belt, but also, in 1995, the first brown dwarfs, which exist in the range of masses above the largest gas giant planets but below that of stars, and so are not capable of hydrogen burning nuclear fusion reactions in their cores. The 1990s also saw the discovery of the first exoplanets, that is planets outside of our solar system, and in 1998 the first free-floating planets were discovered. All of these discoveries put pressure on astronomers to make the definition of planet more precise and reconsider the status of borderline objects such as Pluto. Arguably the straw that broke the camel's back was the discovery in 2005 of Eris—the ninth most massive body directly orbiting our sun, which is 27% more massive than Pluto. Many other large trans-Neptunian objects such as Sedna, Makemake, and Haumea, were also discovered around this time.[23] While no one of these many important scientific discoveries is "the discovery that Pluto is not a planet," they do show that the decision to redefine planet and demote Pluto was not solely a conventional one, but rather one for which new scientific discoveries played a central and defining role.

As LaPorte notes in the context of the species problem, faced with the strain placed on a kind term by discoveries of the preceding sort, scientists generally have one of three possible options available to them (LaPorte 2004, 66). First, they can expand the taxon, granting that things formerly thought *not* to belong to the extension of the term do belong to it after all. This was the approach advocated by Stern and Levinson, that would have kept Pluto as a planet, but also admitted 100 or so more objects as planets, including the Earth's own moon. The second option that scientists have in light of the strain imposed by such discoveries is to pare the unacceptable taxon down, saying that things formerly believed to belong to the extension of the term do not in fact belong to it. This is the approach advocated by Soter and by the general assembly of the International Astronomical Union, which pared the number of planets in our solar system down to eight. Finally, the third option that scientists have available to them, when old taxonomic categories are faltering in light of new

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[22] Alan Stern (2012), PI of NASA's New Horizons Pluto-Kuiper Belt Mission (http://pluto.jhuapl.edu/overview/piperspective.php?page=piperspective_08_24_2012).

[23] Makemake and Haumea—like Pluto—are dwarf planets in the Kuiper belt.

scientific discoveries, is simply to declare the taxon a *folk concept,* unworthy of continued scientific investigation. On this approach the term planet describes only an artificial kind, and while it might remain in ordinary discourse as a cultural term, it would be eliminated from the scientific vocabulary of astronomers and planetary scientists—indeed the very notion of a planetary scientist would become an oxymoron.

Although which of these three options scientists choose to adopt is largely a matter of convention, what was *not* an option for the scientists was to leave the traditional definition and extension of the term planet intact, while having it remain a scientifically *useful* concept. As Soter notes, "ad hoc definitions devised to retain Pluto as a planet tend to conceal from the public the paradigm shift that has occurred since the 1990s in our understanding of the architecture of the solar system. [. . .] To be useful, a scientific definition should be derived from, and draw attention to, the basic principles [of nature]" (Soter 2006, 2518). Natural kinds are a joint venture between the taxonomic practices of human beings and the structure of nature, and as any practicing scientist will tell you, nature is often quite successful in resisting the particular taxonomies we may wish to impose.

6. Conclusion

As I have shown, new insight into the Pluto controversy is gained by drawing out the striking analogy between what I have here termed the 'planet problem' in astronomy and the well-known species problem in the philosophy of biology. I argued that the taxon planet can still be considered a natural kind despite the fact that a) its meaning and recognized extension have changed over time, b) there are multiple scientifically compelling definitions of planet, and c) many of those definitions include historical and/or relational properties. Barring these worries, it is ultimately an empirical question to be decided by astronomers whether the taxon planet is in fact scientifically useful for the organization, explanation, and prediction of phenomena.

I also argued that the decision demote Pluto involved both discovery and stipulation. The important new discoveries about the structure of our solar system that have taken place since the 1990s have often been overlooked in discussions about the Pluto case, which is often painted as nothing more than a debate over semantics. Moving beyond the false dichotomy between discovery and stipulation is important for making sense scientific episodes such as this, where there is a revision in an accepted scientific taxonomy.

Finally, this analysis of the planet problem also suggests that the species problem in biology, instead of being anomalous, may be more typical in science than we had hitherto thought. If it turns out that the sort of taxonomies that science finds most useful are often defined by historical and relational properties, are sometimes permissive of vague boundaries, and are such that there can be multiple scientific definitions in different accommodation contexts, then perhaps the correct conclusion to draw is that the problem lies not with these scientific taxons, but rather with our traditional philosophical conception of natural kinds.

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