1.00 — Setting The Stage

← 000 - Introduction

A Little Background

What Is A Planet?

Well, that depends on who you ask. Offically, according to the International Astronomical Union (IAU), as of 2006[1], a planet is:

1. 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, and (c) has cleared the neighborhood around its orbit.
2. A dwarf 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, (c) has not cleared the neighborhood around its orbit, and (d) is not a satellite.
3. All other objects, except satellites, orbiting the sun shall be referred to collectively as small solar-system bodies.

This (in)famously demoted Pluto from full planet status.

Items **1c** and **2c** are the crux of the debate, specifically the criterion for having “cleared the neighborhood around its orbit”. Some people find that specification too limiting, or even artfully chosen specifically to single Pluto out, since it resides in the inner regions of the Kuiper belt and has several near neighbors, whereas the full planets of the Solar system do not (not counting moons).

Tim DeBenedictis in an article[2] at Space.com, makes a simple and compelling argument that the dividing line should be set more simply at objects of greater than 1000 km radius which independently orbit the Sun. At 1000 km radius, he says, the materials of which a body is formed (be they rock, ice, or metal) will start to deform under their own gravity and the body will become spherical(ish).

His definition is rather simpler than that of the IAU:

1. A planet is a celestial body that (a) is in orbit around the sun, and (b) has a maximum surface radius greater than 1,000 km (620 miles).
2. All other objects, except satellites, orbiting the sun shall be referred to collectively as small solar-system bodies.

I follow DeBenedictis' suggestion (though to avoid some of the complications of existing definitions, I adopt simplified terms):

1. A ***planemo***[3] is a celestial body that (a) is in orbit around a star or stars, and (b) has a maximum surface radius greater than 1,000 km (620 miles).
2. All other objects, except satellites, orbiting a star shall be referred to collectively as ***micromos*** (small star-system bodies; SSSB — moons, asteroids, comets, etc.).

...and I add the following proviso:

3. A ***world*** is a planemo that possesses a surface and/or atmospheric environment that is either ***habitable*** or ***parahabitable***.

Habitable and Parahabitable

I define a *habitable* a planemo as one which is **immediately habitable** by humans; people from Earth could land there, walk out of their craft in their shirtsleeves, and start hiking around learning about the place, its wonders ... and its dangers.

In contrast a *parahabitable* planemo is one that is **provisionally habitable** by human beings through the use of technology like atmospheric domes, pressurized subterranean habitats, etc., which are:

1. On or below the land or water surface; or,
2. Suspended in the atmosphere by natural buoyancy or gravity-countering technology. In other words, the habitat must be in physical contact with the planemo — orbiting platforms do not render a planemo parahabitable.

In cases where either term applies, I'll often use the nomenclature *(para)habitable*.

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> **Hippy**: So, a *world* is a *planemo*, but a *planemo* isn't necessarily a *world*?

Oh, Hi, Hippy! I didn't know you were here! Friends, this is Hiparistarchus Ptolemeus Galileopernicum (Hippy to his friends — though he pretends not to like the nickname).

Yes, Hippy; that is a very good distinction. All *worlds* are *planemos*, but not all *planemos* are *worlds*. That is a good way to remember it, thanks!

BUT... micromos *can* be parahabitable. Make sense?

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> **Keppy**: Through the use of artificial living environments, right? But that would depend on the rest of the planemo's conditions, wouldn't it? I mean, if it's a lava planemo, it would probably need airborne habitats, rather than surface ones?

Aaaand, here's Keppy (Keplarius Braheus), right on cue.

Yes, Keppy; it can get to be a fuzzy definition — but that's really the fun of it. You're not locked-in to a narrow set of choices... you can "fudge" as your needs require.

Physical Properties of Planemos

There are five properties of planemos that can be thought of as *physical properties* — insofar as they describe the planemo physically or a property of the planemo that emerges from the other physical properties. These are:

1. ***Mass*** (m): The total amount of matter present. (*Mass and weight are not the same — weight depends on gravity; mass does not*.)
2. ***Density*** (ρ): The average amount of matter per unit volume — essentially, how tightly packed the planemo's materials are. This depends on both composition (e.g. rock, ice, metal) and, for larger bodies, gravitational self-compression.
3. ***Radius*** (r): The distance from the planemo's center to its surface. Technically, this is derived from the planemo's mass and average density — but more on this in a moment.
4. ***Surface Gravity*** (g): The strength of gravitational acceleration at the planemo's surface — how strongly it attracts objects located one radius away from its center.
5. ***Escape Velocity*** (v): The minimum speed needed to completely escape the planemo's gravity when starting from the surface — how much velocity is

required to leave the planemo entirely.

These are all intricately interrelated in ways that are much more complicated than we need to account for here. For instance, while **radius** *is* derived from **mass** and **density**, it also matters how strongly the mass of the planemo is gravitationally acting on itself. This causes ***gravitational compression***, which means that the matter is forced into a denser configuration than it would otherwise exhibit *if it were not under such intense gravitational pull*. So, it is also true that **density** in some sense is derived from **mass** and **radius**.

Surface gravity and escape velocity are also very dependent on both mass and radius. The farther a point on the surface of the planemo is from the planemo's center, the less gravitational attraction from the planemo it experiences, decreasing according to the ***inverse-square law*** (more on this later). And the weaker the surface gravity, the less energy it takes to overcome it, so the lower the escape velocity.

For our purposes, it is reasonable to simplify things and say:

> Radius is an *emergent property* of the interaction of mass and density.

... and not be too overly concerned about the subtleties.

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> **Keppy**: *Sed ego dico*, right?

Yes; this is our first official invocation of *sed ego dico*, "because I say". No, it's not *entirely physically accurate*, but it's good enough for what we need to accomplish.

Mass and density are also dependent upon what materials the planemo is made of: most planemos are composed of several materials (rock, ice, liquid water, etc.). Rock, itself, can composed of any number of more basic elements and compounds.

And all of these materials have their own inherent densities. Water, for instance, has a density of about 1.0 g/cm³ (and is, in fact the *standard* for material density in the metric system we're using.) Iron, on the other hand, has a density of about 7.7 g/cm³ — almost eight times that of water. So 1 kilogram of water takes up more volume than one kilogram of iron.

> There is an old riddle, which was a favorite of my maternal grandfather: "Which is heavier — a pound of iron or a pound of feathers?" The trick to the question, of course, is that both *weigh* a pound, but because feathers are less dense than iron, that pound (in its natural state) takes up far more volume than does the iron.

Terminology Focus

In much of the published astrophysical literature, the word "size" is often used ambiguously. You'll often encounter a phrase like "an Earth-sized planemo". *Most of the time* "size" means radius, but on rare occasions, it is used to mean a planemo with the same *mass* as Earth, which is a very different quality. It's even worse when the word "big" is invoked... Does "this planemo is three times as big as Earth" mean "three times Earth's **radius**", or "three times Earth's **mass**"?

For our purposes, it is simpler to refer to the properties of a planemo in terms of multiples of the same property for Earth. So while Earth's mass is ≈ 5.972×10^{24} kg, we simply say that Earth has "one Earth-mass".

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> **Keppy**: If you'd *rather* memorize 5.972×10^{24} kg, nobody's going to stop you, but 1.0 is a much easier number to remember, in my opinion.

My point exactly. Earth's mass is ≈ 5.972×10^{24} kg. Mars' mass is ≈ 6.39 \times 10^{23} kg. Big numbers to carry around in your head. But, if we divide Earth's mass by Mars' mass:

$$\frac{5.972 \times 10^{24}}{6.39 \times 10^{23}} \approx 0.107$$

... we find that Mars is about one-tenth as massive as Earth, which is a much easier fact to remember. In the official literature you'll often see this written as "Mars has a mass of 0.107$\oplus$", where $\oplus$ is the astronomical symbol for Earth.

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> **Keppy**: It's originally based on astrology, but astronomers don't like to talk about that.

Ahem, yes, well.... we'll use the same convention here: Earth's mass is 1.0⊕; Earth's radius is 1.0⊕; Earth's density is 1.0⊕ —

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> **Hippy**: *Wait a minute!* They're *all* 1.0⊕??? How do you know whether you're talking about mass or radius or density or ...?

Excellent point, Hippy! Most of the time the context makes it clear which property is being referenced, but here are some ways we'll see it expressed:

- M_{Mars} ≈0.107⊕
- M = 1.0⊕
- "... this would be around 4.25M⊕..."

And the same with radius, density, etc.:

- Mars' radius is ≈ 0.53⊕.
- Mars' density is ≈ 0.173⊕

You're already familiar with this but you may not be aware of it. Astronauts will often talk about experiencing "5g of acceleration". No, that's not the bandwidth of their phone's WiFi. They mean that, for a time, they experienced **five times the gravity** we normally feel at the surface of the Earth. Because this is so often abbreviated *g*, we'll do the same here with the understanding that 1.0g = 1.0g⊕.

Here are some other symbols that will be used in the same way:

- ☉ = the Sun
- ☽ = the Moon
- ♃ = Jupiter

It might be helpful when seeing these symbols to think of them as standing for a corresponding descriptive term; for instance,

- ⊕ = the Earth, or "terran"
- ☉ = the Sun, or "solar"
- ☽ = the Moon, or "lunar"
- ♃ = Jupiter, or "jovian"

So when you see something like "Mars' radius is ≈ 0.53⊕", read it as "Mars' radius is ≈ 0.53 *terran*." Other examples:

- The mass of the Sun is ≈ 333000⊕: "The mass of the Sun is ≈ 333000 *terran*."
- The radius of the Moon is ≈ 0.2727⊕: "The radius of the Moon is ≈ 0.2727 *terran*."
- The mass of Ceres is ≈ 0.0128☽: "The mass of Ceres is ≈ 0.0128 *lunar*."

We say this is expressing these parameters in ***relative*** terms — how the parameter relates to the same parameter of another known body (the **standard**) —, rather than in ***absolute*** terms, such as kilometers, grams, g/cm³, or m/sec².

For instance, the Earth's density in **absolute** terms is ≈ 5.515 g/cm³; in **relative** terms it is 1.0⊕. To arrive at the relative value for a body, divide the absolute value of its given parameter by the absolute value of the same parameter for the standard: e.g.,

$$\rho☽ \approx \frac{3.344\ gm/cm^3}{5.514\ gm/cm^3} \approx 0.606\oplus$$

Bigger and Heavier

Most of the time, we'll talk about planemo masses and radii in relative terms, but in colloquial discourse we might find ourselves simply wanting to, say, compare Mercury and Ganymede by mass and radius.

	Mass	Radius
Mercury	0.055⊕	0.3829⊕
Ganymede	0.025⊕	0.413⊕

Mercury's mass is greater than that of Ganymede but Ganymede's radius is greater than Mercury's. Thus we might simply say "Mercury is *heavier* than Ganymede, but Ganymede is *bigger* than Mercury." While the terms "bigger" and "heavier" are non-technical, they are easily understandable in casual parlance.

Hippy: But "heavier" is a relative measure of **weight** — which is *mass under*

> *gravity*. Mass and weight are *not* the same thing.

No; they are not. And that is why I took this moment to explain. We're exercising a little *sed ego dico*, here, relative (pun intended) to nomenclature.

→ 1.01 — A Basic Planemo

Terminology Roundup

- **Planemo**: a **planetary mass object** (a term coined by Gabor Basri) in orbit around a star or stars that has a maximum surface radius greater than 1,000 km (620 miles).
- **Micromo**: a **micro-mass object —** e.g. irregular moons, asteroids, comets, etc.; also called *small star system bodies (SSSB)*
- **World**: a **planemo** that has a surface environment that is either **habitable** or **parahabitable.**
- **Habitable**: a planemo which is **immediately habitable** by humans.
- **Parahabitable**: a planemo that is **provisionally habitable** by human beings through the use of life-support technology.
- **Gravitational compression**: an increase in a material's density as a result of the action of its own gravitation upon it.
- **Inverse-square law**: A physical law of energy dissipation; the energy of an emanation diminishes by a factor of the square of the distance from the source. Thus, a planemo twice as far from its star as its neighbor planemo receives **one-fourth** as much energy from its star as its neighbor planemo does:

  $$E = \frac{1}{d^2}$$

  ... where *d* is the **relative** distance.
- **Relative reference**: Expressing a parameter in terms of the same parameter for a "standard" example.
- **Absolute reference**: Expressing a parameter in terms of concrete units of measurement, such as meters, grams, liters, etc.

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1. IAU RESOLUTION: DEFINITION OF A PLANET IN THE SOLAR SYSTEM. https://nssdc.gsfc.nasa.gov/planetary/text/pluto_iau_res_20060824.txt ↩

2. DeBenedictis, Tim. “Why Pluto Is a Planet, and Eris Is Too.” Space.com, June 4, 2015. http://www.space.com/29571-why-pluto-is-a-planet-and-eris-is-too.html. ↩
3. Basri, Gibor; Brown, E. M. (May 2006). "Planetesimals to Brown Dwarfs: What is a Planet?". Annual Review of Earth and Planetary Sciences. 34: 193–216. arXiv:astro-ph/0608417. Bibcode:2006AREPS..34..193B. doi:10.1146/annurev.earth.34.031405.125058. S2CID 119338327. ↩