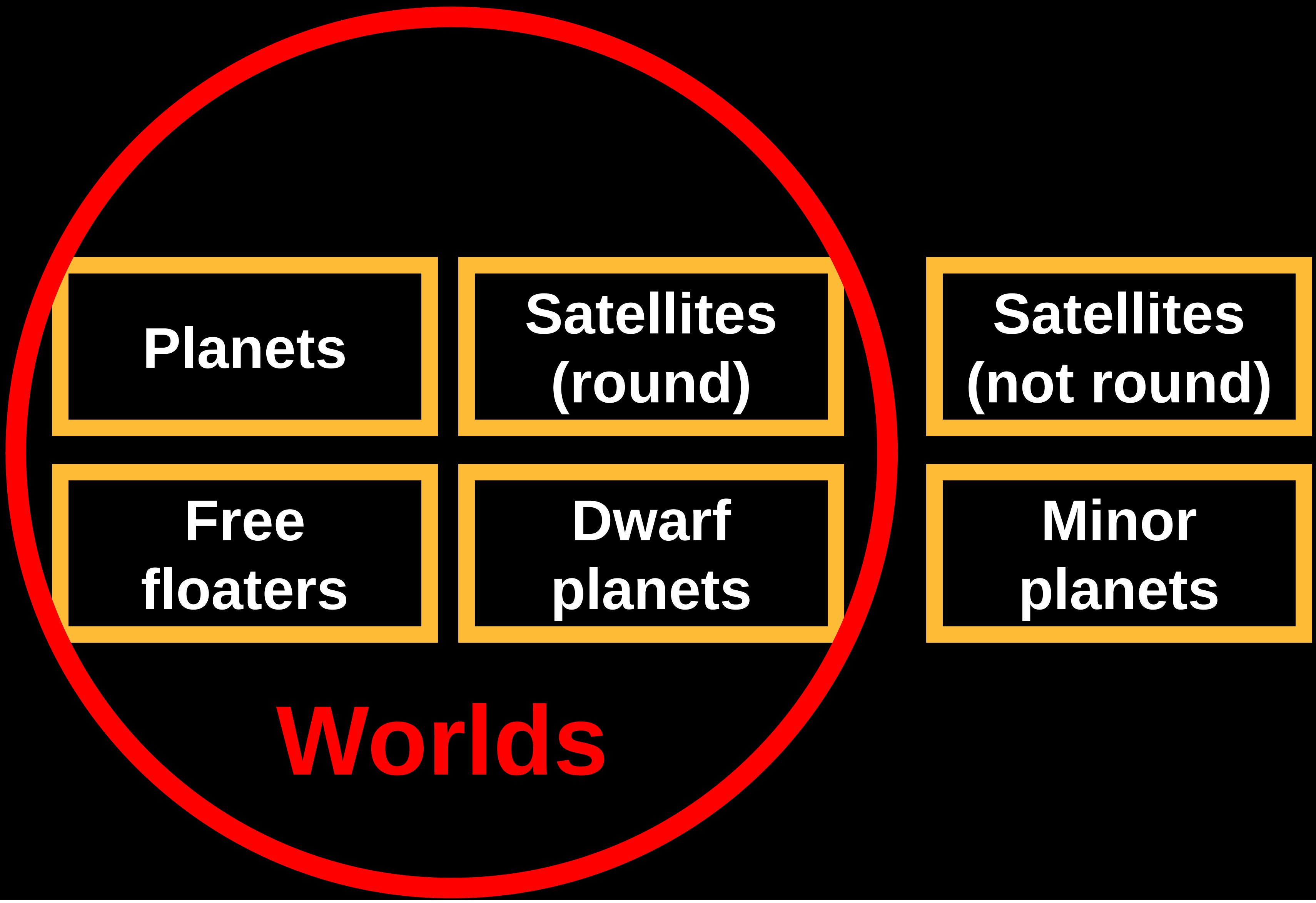
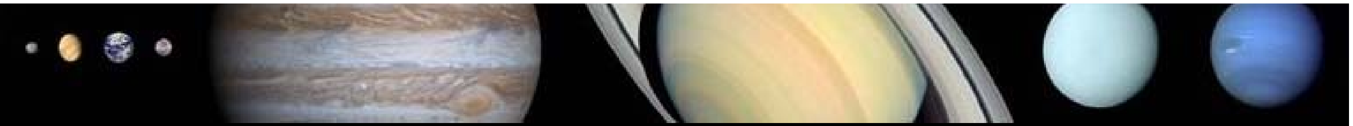
Planetary Taxonomy

Jean-Luc Margot (UCLA) & Hal Levison (SWRI)

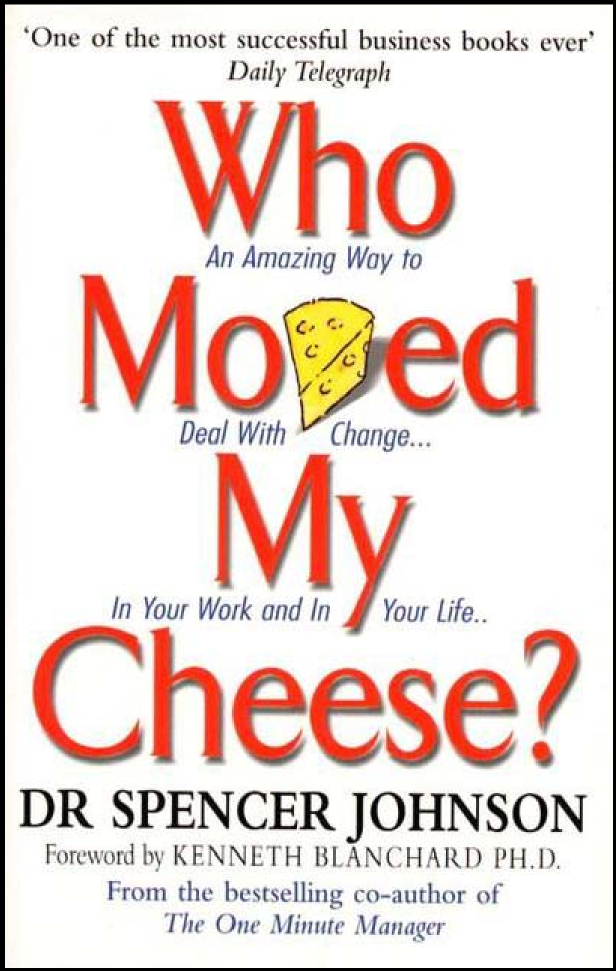




Who moved my cheese?

In August 2006, the International Astronomical Union (IAU) adopted a resolution that defines a planet.

The defining criterion is dynamical in nature, reflecting the etymological origin of the word planet ("wanderer").



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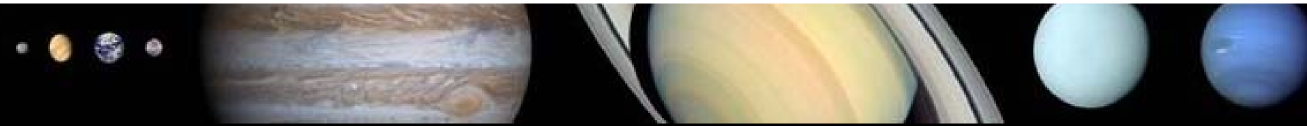
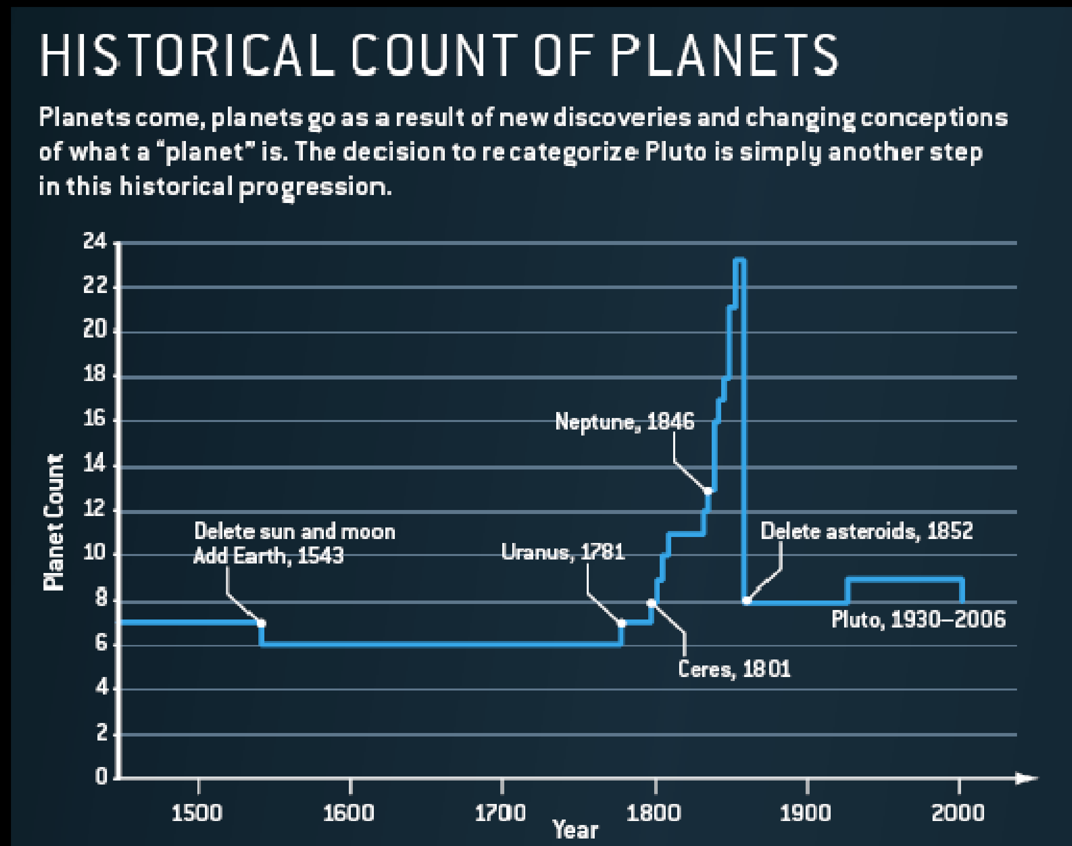


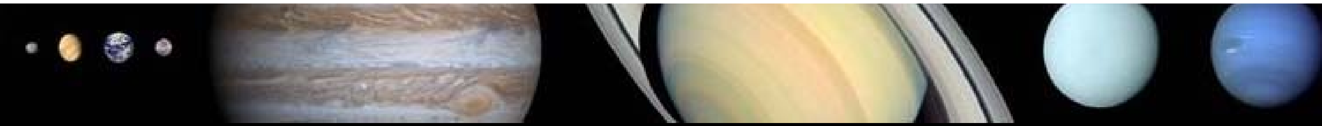
Who moved my cheese?

The IAU definition changed the number of planets in the solar system.

A few astronomers have resisted the change because they prefer a taxonomy based on geophysics and not dynamics.



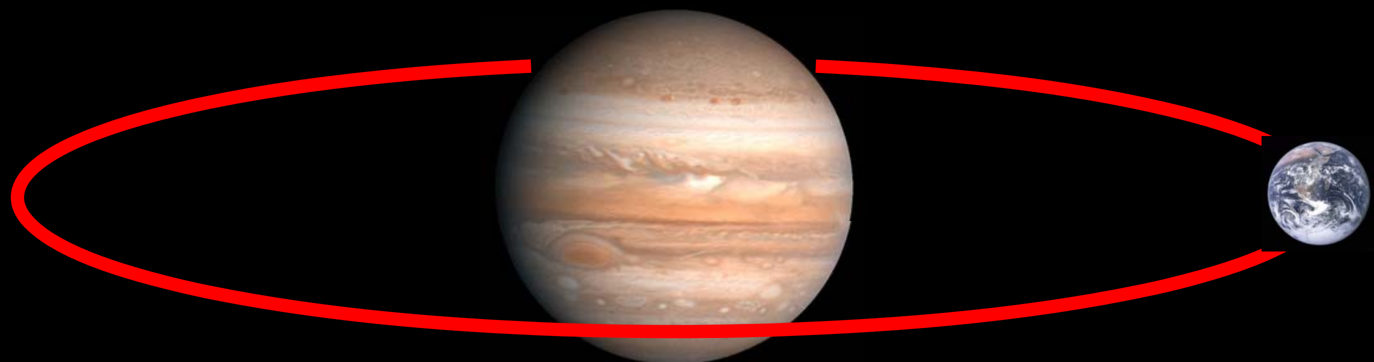
Graphic from Steven Soter, Scientific American, Jan 2007



Is it still cheese if I move it?

Taxonomies based on geophysics and dynamics give different answers to thought experiments in which Earth loses its dynamical dominance.

If Earth is placed in orbit around Jupiter, is it still a planet? Is Earth still a planet if it becomes a Jupiter trojan, is moved to 100 AU, or becomes a free floater?



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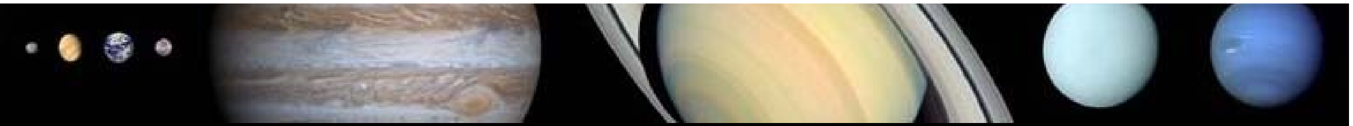
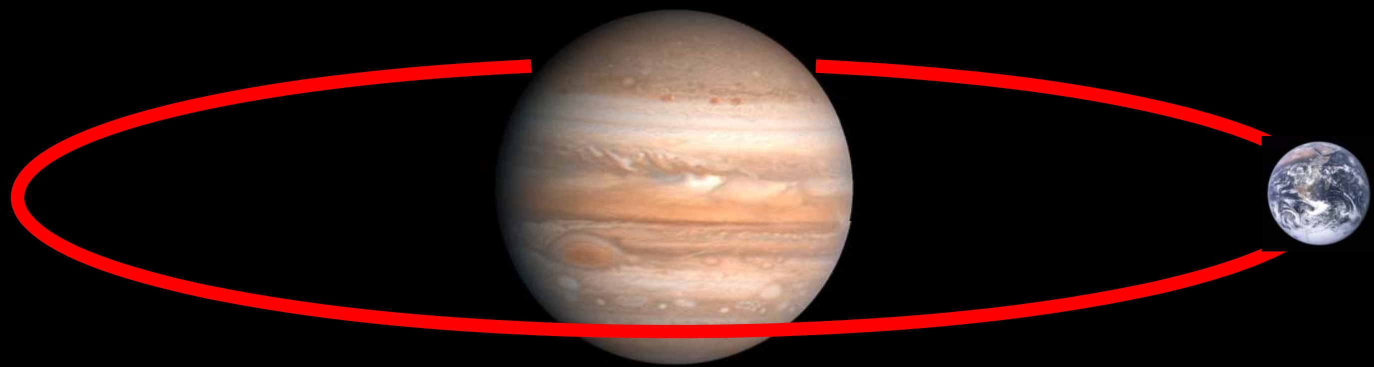


Is it still cheese if I move it?

In a self-consistent geophysics-based taxonomy, the answer is YES. Planetary status is determined by intrinsic properties ("roundness"). It is context-independent and the Earth remains a planet whether it is moved to 5, 100, or 2000 AU.

The inevitable consequence of a geophysics-based taxonomy is that we must abandon the distinction between planets and satellites.



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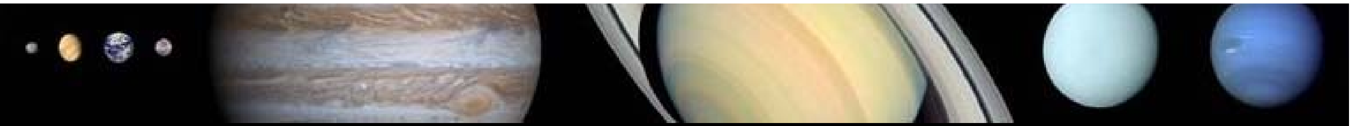
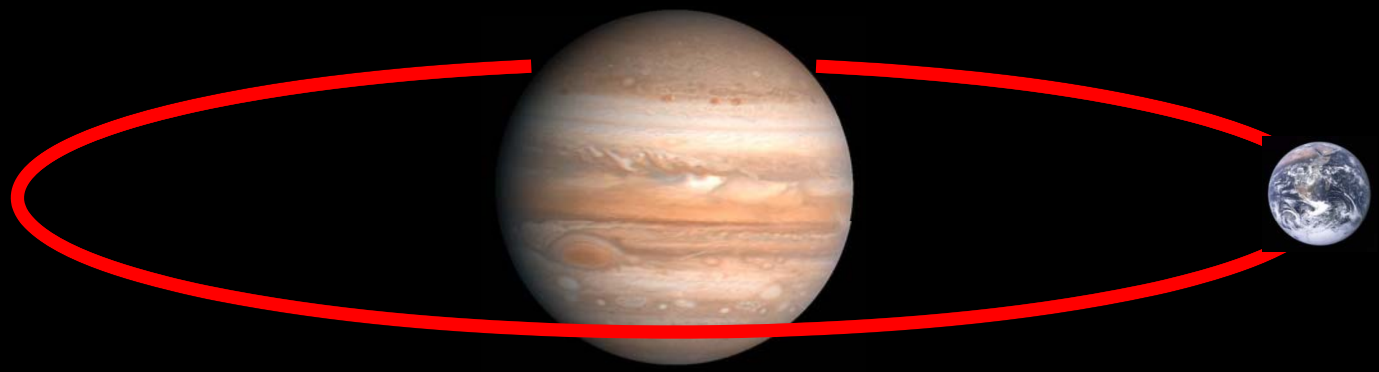


Is it still cheese if I move it?

In a self-consistent dynamics-based taxonomy, the answer is NO. **Planetary status is determined by dynamics (orbits a star, dynamical dominance). It is context-dependent, as are magma/lava, meteoroid/meteorite, cloud/fog.**

We must accept the fact that planetary bodies that are geophysically similar may belong to different taxonomic classes, depending on the dynamical environment.



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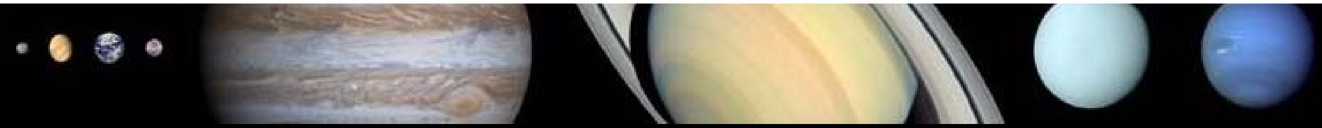
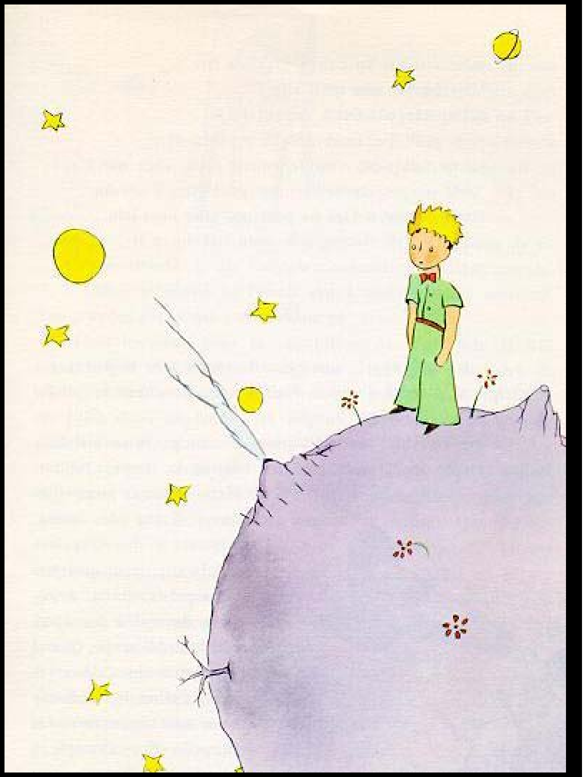


An unnecessary conflict

Although planetary taxonomy is based on dynamics, a geophysical criterion is not without merit.



"Roundness" can be used to define the subset of bodies for which gravitational forces exceed material strength.

A "world" is an apt name for such bodies, and this classification need not be in conflict with the dynamics-based taxonomy of planets and satellites.

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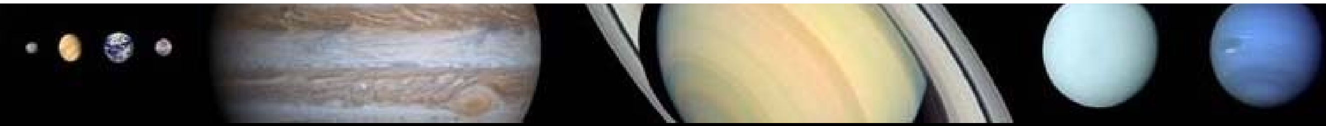


A simple proposal

Planets

Satellites (round)

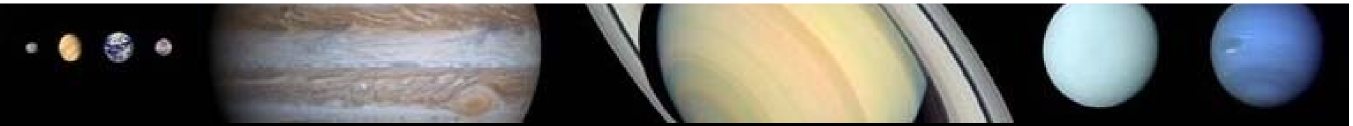
Satellites (not round)

Free floaters

Dwarf planets

Minor planets

Worlds



Quantifying dynamical dominance

The scattering parameter $\Lambda \sim M^2/P$ quantifies the extent to which a body scatters smaller masses out of its orbital zone in a Hubble time (Soter, 2006).

It is the ratio of two directly observable properties (mass M and orbital period P) which makes it convenient for classification.

Dynamical dominance is one of the easiest properties to establish.

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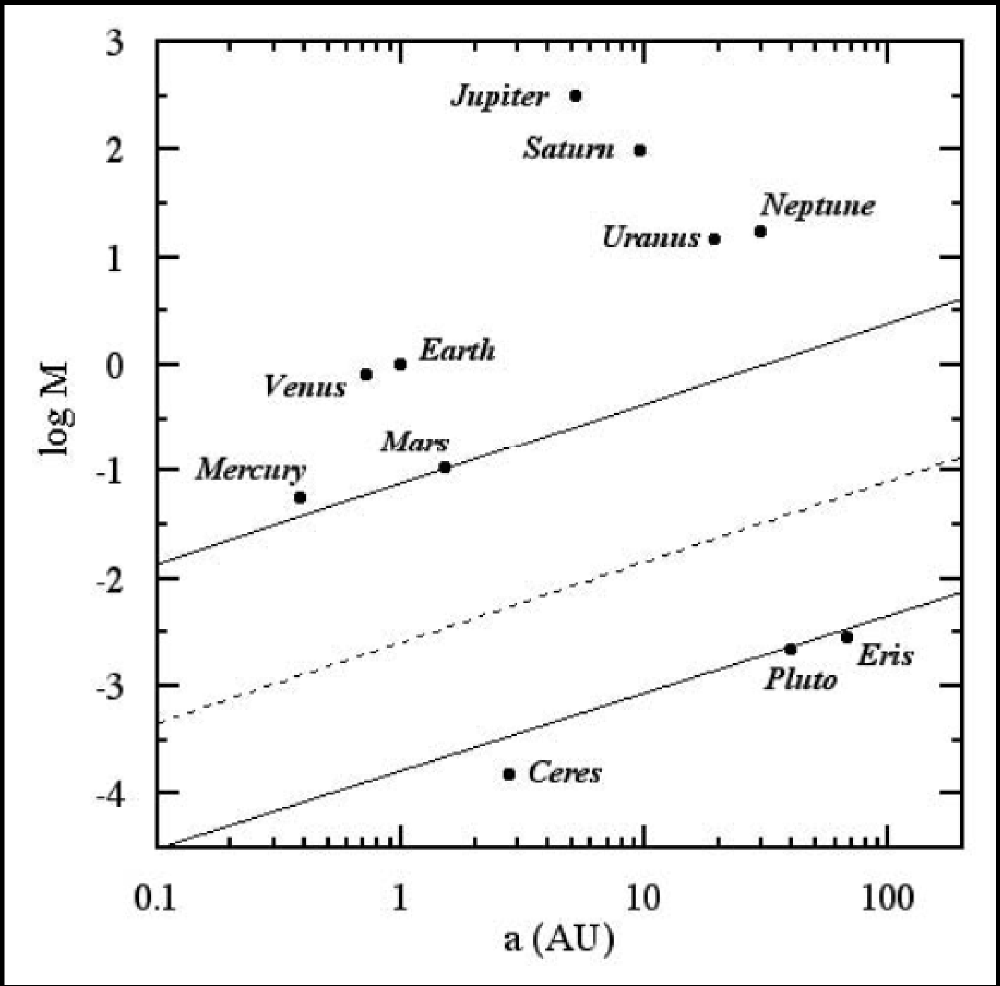
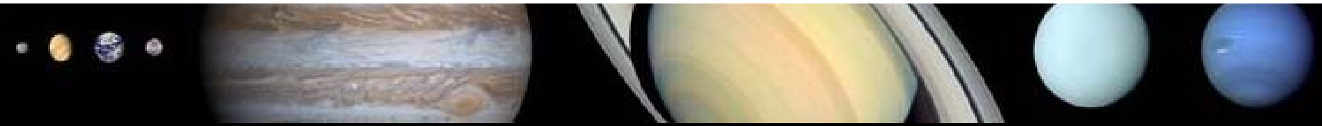
Quantifying dynamical dominance



Mass M (in Earth masses) vs. semimajor axis a for solar system bodies.

The solid lines illustrate a difference of 5 orders of magnitude in the observed values of the scattering parameter **Λ~M^2/P** *for planets and non-planets. The dashed line is Λ=1.*

From Soter (2006).



Quantifying roundness

Roundness is almost never directly observable and is therefore inherently problematic as a basis for classification.

Can we use size or mass as a proxy to establish roundness? The critical diameter D above which a self-gravitating body of density ρ overcomes material strength S is of order:

$$D \sim \frac{1}{\rho}\sqrt{\frac{3}{2\pi G}}\sqrt{S}$$

(Tancredi and Favre 2008)

The strength of planetary materials depends on temperature, constituents, and mixing ratios. It spans a wide range of values: 1-10 MPa for water ice near freezing and 100-200 MPa for terrestrial rocks.

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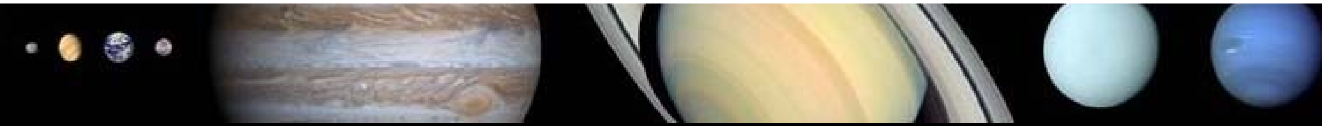
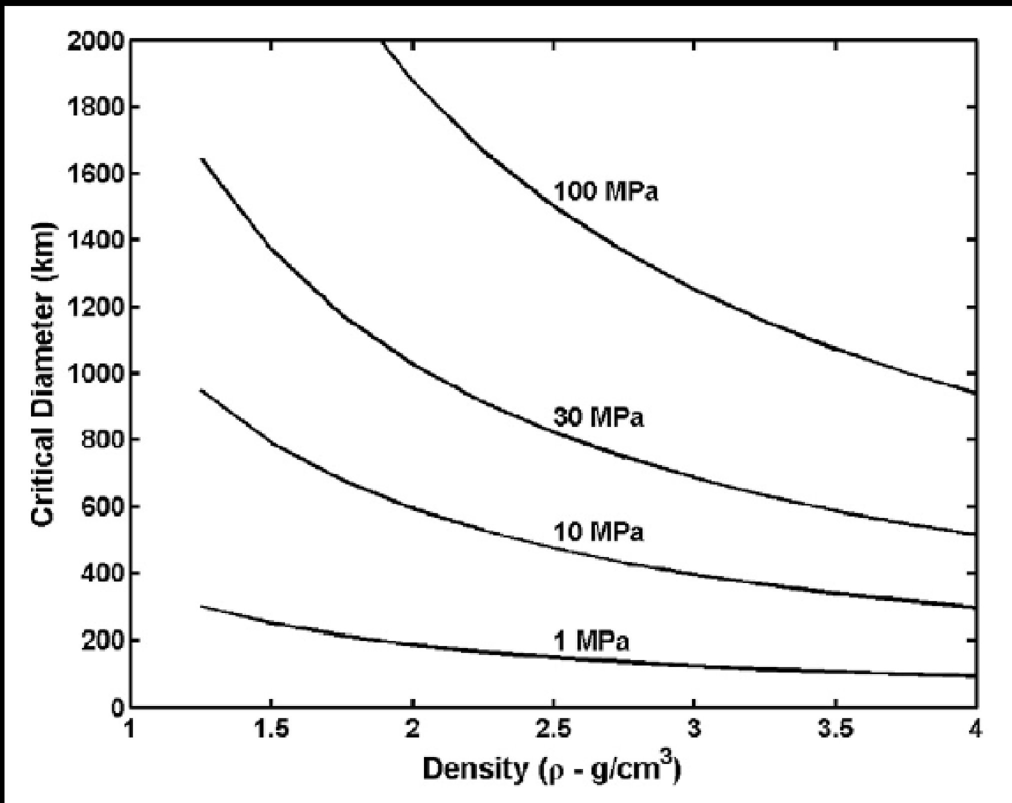
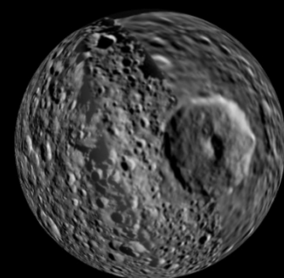


Quantifying roundness



The size threshold at which a body becomes round is highly uncertain, perhaps 200-1200 km.



Mimas (395 km)

Vesta (538 km)

Theoretical estimates of the critical diameter at which a self-gravitating body overcomes material strength (Tancredi and Favre, 2008).

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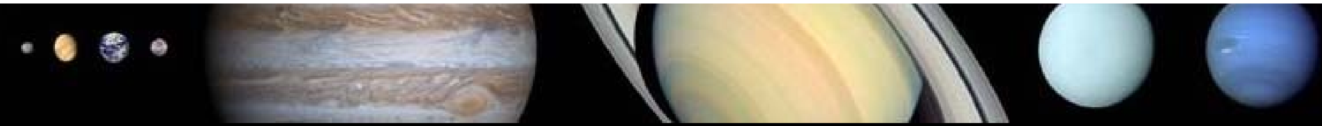


Quantifying roundness

Roundness is almost never directly observable.

Using mass or size as a proxy yields inconsistent results.

The degree of roundness is a continuum and shows no clear transition.

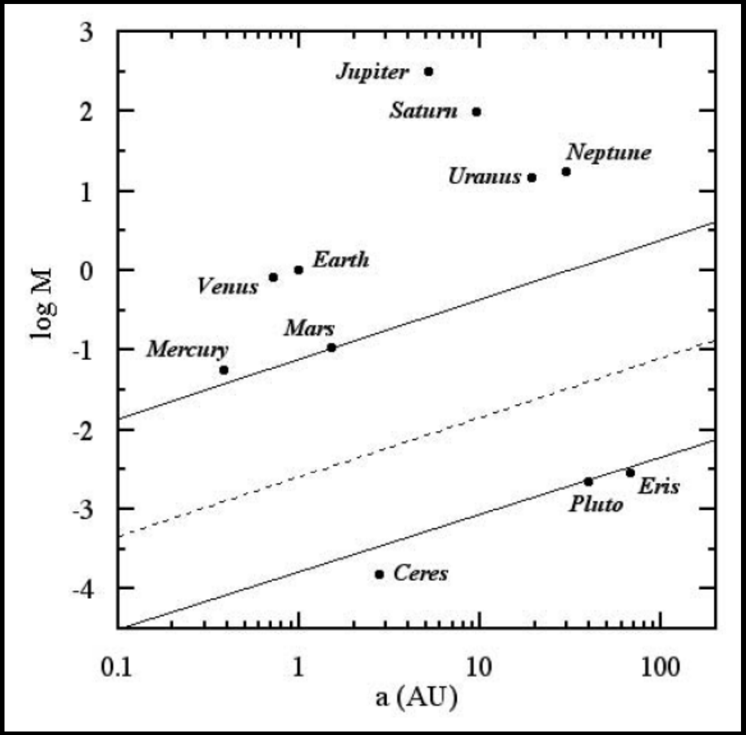
A taxonomy based on roundness is highly problematic.

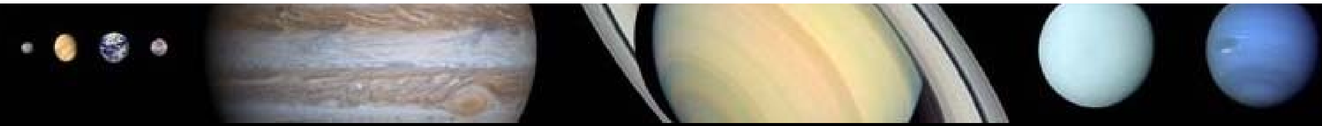
We can tolerate some uncertainty in establishing the "world" status of a newly discovered object, and still establish its planet or satellite status with existing dynamical criteria.

All dynamically dominant bodies exceed the threshold for roundness

All dynamically dominant bodies at distances 0.1-100 AU from the host star are larger than ~1200 km, which exceeds the most stringent size threshold for roundness.

Not all round bodies are dynamically dominant.





Recommendations

The IAU definition of planet can be solidified in three ways:

1) **Replace "orbits the Sun" with "orbits a star" to make the definition applicable to exoplanets.**

2) **Make the definition more rigorous by adopting an explicit criterion for dynamical dominance (such as a threshold on the directly observable scattering parameter $\Lambda \sim M^2/P$).**

3) **Because all dynamical dominant bodies exceed the size threshold for roundness, the IAU should consider dropping the roundness criterion from the definition. It is redundant and not directly observable.**

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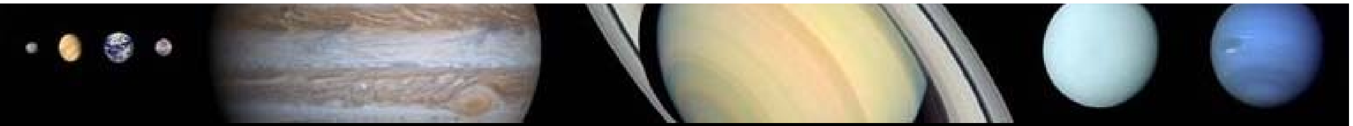

Conclusions

- **Create a class to recognize that round bodies share some special properties.**
- **New class need not be in conflict with existing dynamical-based taxonomy of planets and satellites.**
- **Label all round bodies "worlds". Some worlds are planets, others are not.**