Pluto – An Enduringly Interesting Celestial Object

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Pluto is a celestial object that had caught the imagination of increasingly 'sky-aware' people all around the world, perhaps due to the inspiring story of its discovery by a young amateur astronomer. It was celebrated as the ninth planet of the solar system for decades. A question mark hung over its nomenclature as a planet from the time of the discovery of its moon Charon, when a good estimate of its very small mass in comparison with other planets was obtained. The discovery of UB 313, a body in the outer regions of the solar system that was more massive than Pluto, magnified this question mark and compelled the International Astronomical Union to review the definition of the word 'Planet'. A new and physical definition was given to this word and Pluto was categorized as a dwarf planet. The beauty of this physical definition of a planet is something that would definitely have been appreciated by Clyde Tombaugh – who once made this beautifully simple statement about Pluto, while its status was being questioned – "It is there, whatever it is". Yes, whatever it is, Pluto is one celestial object that is somehow very endearing to everyone around the world and is also an object whose studies are compelling certain paradigm shifts in our understanding of the structure and evolution of the solar system.

Pluto will always remain an enduringly interesting object in the sky, regardless of any changes in its nomenclature. One reason it holds a place in the imagination of many could perhaps be due to the fact that the story of its discovery is a very inspiring one for every enthusiastic amateur astronomer.

Keywords
Planet, asteroid, retrograde motion, trans-Neptunian object, Kuiper belt object.

Pluto was discovered by a 22 year old amateur astronomer Clyde Tombaugh, whose committed interest to observational astronomy was recognized by the Lowell Observatory. This recognition came after he submitted to the observatory his observations of the

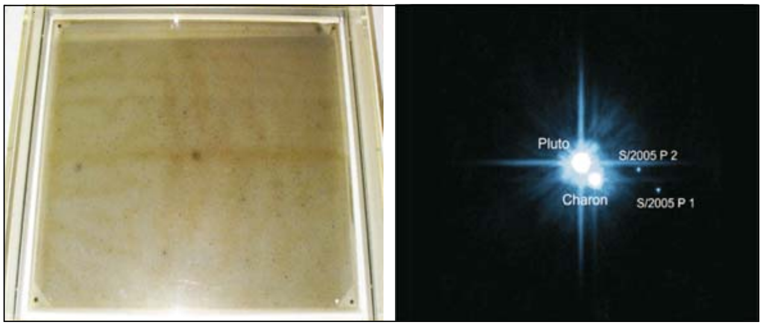

Figure 1. Discovery plate of Pluto and a recent HST image of Pluto with its moons Charon, Nix and Hydra.

planet Mars obtained with his handmade telescope. He was then given telescope time at the Observatory and asked to scrutinize sky images. This was to look for the 'Planet X' that had been proposed by Percival Lowell as the culprit that could explain perturbations in the orbits of Uranus and Neptune.

Looking further back in time, we arrive at the first usage of the word 'planet' by Greek astronomers. Scanning the skies all night, and then, night after night, they concluded from their observations that stars and constellations formed a fixed background in the sky against which certain 'wanderers' or 'planets' had anomalous movements. These anamolous movements were generally West to East. Sometimes the planets had movements in the reverse or 'retrograde' directions. Following a short phase of retrograde movement, the planet would come back to the 'prograde' direction of motion, making interesting loops in the sky, against the background of the fixed stars and constellations. Kalidasa has described such a retrograde movement of Mars in his '*Malvikagnimitram*'.

There were five of these planets that could be observed without any optical aid. They were observed by sky gazers for many millenia before a telescope was finally turned towards celestial objects. Galileo's observations from 1609 AD revealed that planets could be resolved as disks when viewed through telescopes, while stars remained as pin points of light even when viewed through increasing aperture instruments. The usage of telescopes also revealed fainter and fainter objects in the skies. It was in 1781 finally, that William Herschel with his 60-foot telescope, found a new object in the sky which was also a wanderer – its position changed slowly against the background of the fixed stars. This was the planet Uranus.

In 1801, Guiseppe Piazzi discovered an object in between the orbits of Mars and Jupiter where a planet was expected. This object was then named Ceres and was counted as a planet. Several other celestial objects were found, one after another, in orbits very close to that of Ceres. The number of planets seemed to be growing far too rapidly! By the 1840s, the mass estimates of these newly discovered planets became better, and it was known that their masses were much smaller than those of all known planets. These objects could also not be resolved as disks when viewed through the highest powered telescopes that were then available. Herschel then suggested the nomenclature of 'asteroid'[1] or 'star-like' for these objects that could not be resolved as disks, unlike the naked eye planets and Uranus. Ceres heralded as a new planet in 1801, was downgraded to the status of an asteroid within a few decades. There perhaps, had not been all that much of a resistance to this change in nomenclature as the list of planets had been changing from year to year in those decades and Ceres was not at all seen as an object that was special in any way.

[1] **Asteroids:** A group of relatively small rocky objects in the solar system, the main body of which have orbits in between that of Mars and Jupiter.

It was around this time that the next planet Neptune, was discovered. Perturbations in the orbit of Uranus gave rise to theoretical predictions of the existence of a planet beyond Uranus. The actual discovery of Neptune followed these predictions. *Figure* 2 is a cartoon that symbolized the reaction of newspapers to this new method of searching for planets – through mathematics!

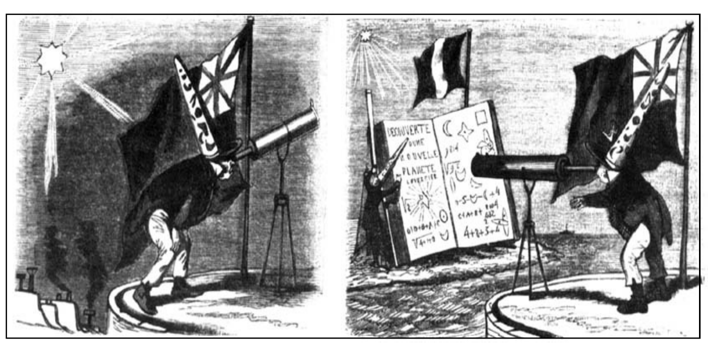

Figure 2. A cartoon published in France at the time of the discovery of Neptune. (Courtesy http://www-history.mcs.st-and.ac.uk/Extras/Adams_Leverrier.html)

From detailed observations of Neptune, it was clear that here was a celestial object that was very different from the class of objects that had been found in orbits between that of Mars and Jupiter.

Neptune, it seemed was not sufficient, however, to explain all the perturbations noticed in the orbit of Uranus. Percival Lowell made detailed calculations of the possible orbit of a Trans-Neptunian[2] planet and started a search program for this object. This was to become famous as the search for 'Planet X'.

The story of finding a new planet, very close to the predicted position of Lowell's Planet X, by the painstaking work of Clyde Tombaugh is very inspiring (see pp.2–3 of this issue). The search for the 'Planet X' had started in 1906 and seemed to have culminated in a spectacular agreement of theoretical predictions and observations, through Tombaugh's discovery of Pluto, in 1930. *Figure* 3 shows an estimate from the 1930s that showed the agreement between the predictions of Lowell, for the Planet X and the known orbit of Pluto after its discovery.

In the years following the discovery of Pluto, there was a wealth of romance attached to the entire process of the predictions for its existence and its ultimate detection. Notes from 'The Observatory' lament the absence of any reference to a 'new planet swimming into anyone's ken' [3]. Perhaps Keats was forgotten in the tremendous excitement that the real discovery of a new planet had raised. However, there was an oblique reference to this connection noted in the same publication (*Figure* 3) – a satirical poem that had much less to do with the new planet Pluto than with drunkenness and magistrates (*Figure* 4).

It was also realized that there had been earlier images, notably Lowell Observatory plates from 1915 that did capture Pluto, but had not been recognized for what it was until after its discovery in 1930. *Figure* 5 is a reproduction of a table showing all the possible pre-discovery observations of Pluto that were tabulated in a Lick Observatory Bulletin.

[2] **Trans-Neptunian objects:** A small planetary body in the outer solar system, in an orbit with a semi major axis greater than that of Neptune's orbit.

[3] Keats wrote "On first looking into Chapman's Homer" with the very interesting comparison of a first reading of Chapman's translation of Homer with the wonder experienced by "a watcher of the skies when a new planet swims into his ken" in 1816, 35 years after Herschel's discovery of Uranus and at a time when many asteroids were being discovered and creating the excitement of a new planet discovery every few years.

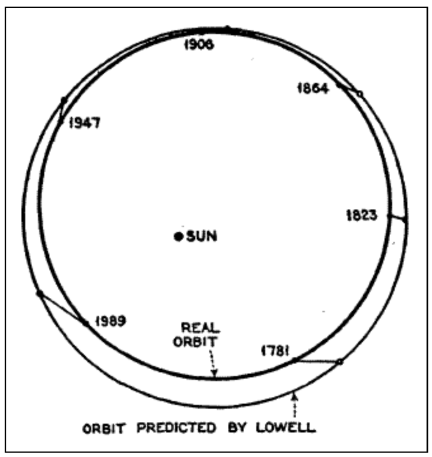

Figure 3. Orbit predicted by Lowell and a 1931 estimate of the orbit of Pluto.

Figure 4. A reproduction of a poem very glancingly referring to the exciting new discovery of a ninth planet of the solar system, in 1930, from 'The Observatory', Vol.53, pp. 213–220, 1930.

In a distant land of the brave and free,
Where there's neither bar nor barley-bree—
At least there isn't officially—
An astronomer, bored with infinity,
Took a sip or two or possibly three
As he scanned the brilliant heavens;
A fourth one scattered his old *ennui*,
And a fifth undoubtedly made him see
The stars at sixes and sevens.
"By heck, that's great!
Come, Sadie," he cried, "and tell me
How many planets there ought to be."
She answered, "Eight."
And he said, "One over the eight for mine;
The old solar system's now got NINE
It swam into my ken;
I'm glad I sat so late;
If I stay any longer I may see ten,
For I've had one over the eight."

Lowell's estimate for the mass of the 'Planet X' was about 7 times the mass of Earth, in order to account for the perturbations seen in the orbits of Uranus and Neptune. Planet X was expected to be another of the ice giants like Uranus or Neptune. Based on this prediction for its mass and its observed magnitude, many estimates were made of its probable properties, in the years

Figure 5. A reproduction of a data table from a Lick Observatory bulletin of 1930, showing possible, pre-discovery images of Pluto.

PREDISCOVERY OBSERVATIONS* AND DISCOVERY NORMALS

G. C. T.	α(1900.0)	δ(1900.0)	Observer — Reducer	Place	Inst.	Authority	Δα	Δδ
1914 Jan 23.7904[a]	89°16′28″.2	+17°37′20″.2	Kaiser—Wolf	Königstuhl	P	Letter	+2″.0	+0″.6
Jan 23.7905[b]	16 32.7	37 19.0	Kaiser—Wolf	Königstuhl	P	Letter	+6.5	−0.6
1914 Nov 12.326	91 48 8.4	+17 52 33.6	? —Boyd and Bower	Harvard	P16[in]	Letter	+1.9	+0.1
1915 Mar 19.2639	89 56 3.8	+18 4 42.2	? —Lampland	Flagstaff	P9	Letter	+3.0	−2.7
Apr 7.1674	90 2 10.8	7 56.7	? —Lampland	Flagstaff	P9	Letter	+3.8	−4.8
1919 Dec 28.1861[c]	96 50 35.1	+19 23 1.0	Humason—Nicholson	Mt. Wilson	P10	Ap.J. **73**, 7	+2.5	+0.6
Dec 28.2861[e]	50 22.3	23 2.9	Humason—Nicholson	Mt. Wilson	P10	Ap.J. **73**, 7	−2.5	+1.9
Dec 29.4285[c]	48 59.0	23 10.5	Humason—Nicholson	Mt. Wilson	P10	Ap.J. **73**, 7	+3.1	+1.7
Dec 30.3660[e]	47 44.1	23 15.0	Humason—Nicholson	Mt. Wilson	P10	Ap.J. **73**, 7	+1.2	−0.2
1921 Jan 29.0896[d]	97 23 53.2	+19 44 33.3	Barnard—VanBiesbroeck	Williams Bay	P10	A.N. **239**, 118	−5.7	−0.7
Jan 29.0896[d]	23 57.3	44 33.8	Barnard—VanBiesbroeck	Williams Bay	P6	A.N. **239**, 118	−1.7	−0.2
1925 Dec 23.2823	104 32 37.0	+20 58 38.0	Strömberg—Mayall	Mt. Wilson	P10	Letter	+1.4	+0.3
Dec 23.3441	32 30.8	58 38.1	Strömberg—Mayall	Mt. Wilson	P10	Letter	+0.2	−0.2
1927 Jan 6.250[e]	105 33 59.6	+21 15 46.8	Ross	Williams Bay	P3	A.N. **239**, 117	−2.2	−3.5
Jan 27.8942	5 51.0	20 6.8	Delporte	Uccle	P	B.C.A.C. 292-3	+2.9	+0.6
1930 Apr 24.1151	108 32 55.8	+22 12 31.4	(normal of 103 observations)				−0.7	+0.1
1930 Oct 1.4906	112 2 31.0	+21 55 31.5	(normal of 8 observations)				−0.7	+0.1

* All prediscovery observations received to date of issue of this paper are included.
a Images very faint, distorted, and unsharp, 2¼° south of center.
b Very doubtful.
c Large images 4° south of center.
d Diffuse images 3°.2 from center.
e Sharp images 6° from center.

Property	Value for Pluto	Value for Earth	Remarks
Mass	$1.254 * 10^{22}$ Kg	$5.9736 * 10^{24}$ Kg	0.0021 Mass of Earth
Semi Major axis	$5.906 * 10^{9}$ Km	$1.496 * 10^{8}$ Km	
Diameter	2274 Km	12756 Km (Equatorial) 12714 Km (Polar)	
Rotation Period	6.405 days	23.9345 hours	
Orbital Period	90,465 days	365.256 days	Pluto's orbital period is 247.68 Earth years!
Axial Tilt	122.46^{o}	23.45^{0}	Pluto rotates with its poles almost in its or bital plane.
Orbit Inclination	17.15^{o}	_	Orbit inclination is with respect to the orbit of the Earth.
Orbit Eccentricity	0.2488	0.0167	
Albedo	0.49–0.66	0.376	
Oblateness[4]	0.0	0.003	Mercury and Venus are the other objects with an oblateness of zero.

Table 1: Physical and Orbital Characteristics of Pluto

following its discovery. John Q Stewart estimated 'the planet's density between 6 to 7 times that of water; its diameter, 14,000 miles; its angular diameter, 0.7 of a second of arc[5], or about 0.25 the apparent diameter of the moon; the force of gravity on its surface more than twice that of Earth, so that with a spring balance, a 150-pound man would weigh something like 325 pounds on the planet! He also estimated that it reflects about 4 percent of the light falling on it, so it would be little brighter than a 'coal pile'. Compare these predictions with the present day estimates of known parameters related to Pluto, from *Table* 1.

1930 estimates of the mass of Pluto based on the perturbation it produced, in the longitude of Neptune, was 1.08 ± 0.23 mass of the Earth. By 1931, the estimated upper mass limit of the planet Pluto was down to one half the mass of Earth, when Brown (1931) showed that the perturbations in the longitude of Uranus would not be useful in the determination of the orbit of Pluto.

[4] **Oblateness:** A measure of the degree to which the shape of a celestial body deviates from a perfect sphere. Planets and stars that are rotating tend to bulge at their equators to a degree that increases with speed of rotation and also depends on whether the body is solid or fluid. The shape taken up by the body is described as an oblate spheroid.

[5] **Arc second:** An angle of a degree is divided into 60 minutes of arc, and a minute of arc is further divided into 60 seconds of arc.

In 1936, calculations by Lyttleton suggested one interesting possibility (as yet unconfirmed) that Pluto may have been a satellite of Neptune and a perturbing encounter may have flung it out of the Neptune system and converted its orbit into that of a direct orbit around the Sun. This encounter may then have also been responsible for making the spin of Triton, the largest moon of Neptune, retrograde.

An estimate of the rotation rate of Pluto was obtained by Walker and Hardie (1955) by analyzing photometric light curves of Pluto.

The 1978 discovery of Charon, a moon (?) of Pluto, substantially improved the mass estimates of Pluto and bought it down to 0.0021 the mass of the Earth. During the period from 1985 through 1990, Earth was aligned with the orbit of Charon around Pluto such that an eclipse could be observed every Pluto day. This provided an opportunity to observe albedo[6] changes with these eclipses in Pluto, to the first accurate determination of the sizes of Pluto and Charon and from there, a better estimate of their masses. A question mark then started hanging over the status of Pluto – was it justified to call it a planet when its mass seemed so small, smaller than our own Moon?

[6] **Albedo:** The proportion of the light falling on a body that is reflected. Albedo may be expressed as a fraction between 0 (perfectly absorbing) and 1 (perfectly reflecting) or as an equivalent percentage.

In the decades following the discovery of Charon, the question mark standing over the status of Pluto started rumbling again, as many Trans-Neptunian objects were being discovered that seemed almost as massive as Pluto – Sedna, Quoar and so on. The question mark became intolerably bothersome with the 2003 discovery of UB 313 or Eris, with mass larger than that of Pluto. If Pluto was a planet, then what about UB 313? If this was the 10th planet, then what was the limit separating Pluto and UB 313 from objects like Sedna and Quoar which did not seem to be categorically different from the former two?

Pluto seemed rather different from the other planets in many respects. Pluto's orbit is highly eccentric. At times it is closer to the Sun than Neptune (as it was from January 1979 through February 11, 1999). Pluto also rotates in the opposite sense from most of the other planets. Pluto is locked in a 3:2 resonance with Neptune; which means that Pluto's orbital period is exactly 1.5 times longer than Neptune's.

Oblateness of a celestial body is a preliminary indication of the extent of differentiation that the body has undergone. The zero oblateness of Pluto is an interesting indication of a complete absence of differentiation in it.

The orbital inclination of Pluto is much higher than that of all the other planets. It might appear that Pluto's orbit crosses Neptune's, but no, we do not really need to worry that Neptune and Pluto would ever collide:

The orbit inferred for Pluto, with respect to that of the other outer planets as illustrated in 1930 (courtesy Frederick Leonard), has been superposed with a modern day illustration (courtesy: Mike Brown) of the orbit of Pluto and UB 313, for comparison, in *Figure* 6.

All these characteristics of Pluto have always put it in a unique category among the planets of the solar system— it is a planet unlike all others. To properly classify the objects in the solar system, a new definition of the word 'planet' was adopted in a resolution of the International Astronomical Union in August 2006. It seemed Sadie in the 1930s poem talking of eight planets was right – the solar system has decided that it is a family of eight planets.

This definition leaves poor Pluto, out in the cold! It leaves us with eight classical planets. And, we have a new class of objects defined as *dwarf planets* – Pluto is one of them.

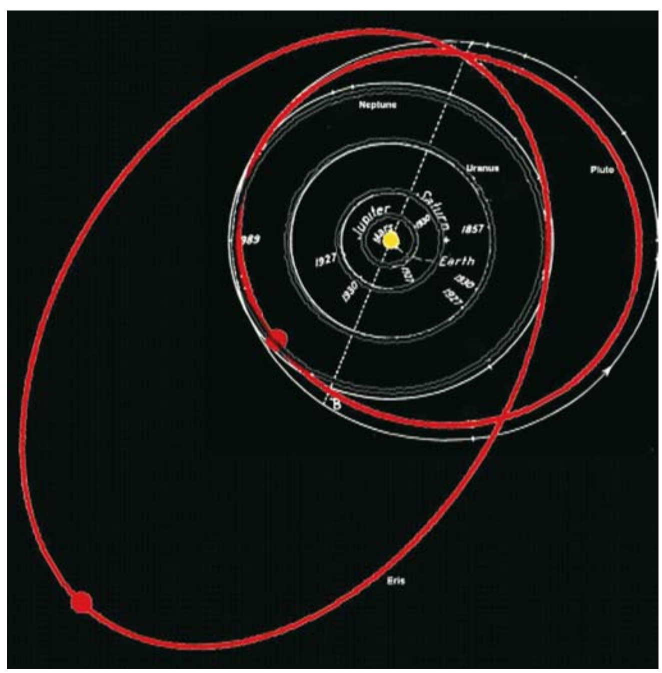

Figure 6. A superposition of orbits of the outer planets estimated in the 1930s with that of a modern day estimation. It can be seen clearly that some errors existed in the estimates of the orbits of Neptune and Pluto, while the overall agreement is remarkable.

Box 1.

The new physical definition calls any object a planet that is in orbit around the parent star, is sufficiently massive that its inward gravitational pull makes the object spherical and is also sufficiently massive that it clears its own neighbourhood of matter – that is, the planet is the Monarch of all it surveys, in its own backyard. A planet has to be the dominant body in its neighbourhood.

These dwarf planets orbit the Sun and are massive enough to be round, but not necessarily the dominant objects in their neighbourhood.

Every school child reacts to the name of Pluto with an involuntary thought – perhaps, something like "*Bechara Pluto…*". There have been many school children the world over who have felt deeply saddened by the removal of Pluto from the list of the nine planets. Many, however, have been expressing it rather confusedly, asking why Pluto has been thrown out of the Solar System. There was a school student from Chennai who had this question to pose on a discussion program on NDTV – "Yes, Pluto is very small, much smaller than the other planets. But, surely, parents will not throw out a malnutrition child away from the family. Why has Pluto been thrown out?"

No, Pluto has not been thrown out of the Solar System; only the class it belongs to in the Solar System has changed. Such changes in classifications are always necessary in science as we uncover more and more data. The story of the renaming of Pluto, from the category of planets to that of dwarf planets, was looked at from a historical point of view, until now. The term 'Planet' initially referred to a celestial object that wandered against the background of fixed stars, in the sky. Later, some of these wanderers were seen to be very small objects that could not be resolved as disks and they were termed asteroids. One object, Pluto, discovered in the outer regions of the solar system, was erroneously thought to be as massive as the terrestrial planets, and was known and loved as the ninth planet of the solar system for decades. When objects larger than the actual known mass of Pluto were being discovered, an attempt was then made to physically define the term planet. It might have seemed as if this redefinition arose out of a cultural necessity of having a reasonable number of planets in the solar system whose count does not change every year, as newer and newer minor bodies of the solar system are discovered. Convenience aside, the point of relevance here is to note that the definition arrived at, for the term 'planet', was ultimately a very physical definition that does make a lot of sense.

Are there any distinctive physical properties that differentiate between the eight classical planets and the newly defined dwarf planets? Are there physical characteristics that are different between the dwarf planets and a whole lot of rubble that is present in the solar system?

Are there any distinctive physical properties that differentiate between the eight classical planets and the newly defined dwarf planets?

Looking at objects on the basis of their sphericity (there, the new planet definition is also compelling us to create new English words!) reflects on the ability of a planetary conglomeration to accumulate sufficient matter in itself, so that its self-gravity dominates over other influences in its vicinity. Gravity dominates and pulls all the planetary material inward, compelling a spherical shape for the object. There are of course, spherical moons of the planets – like the Galilean moons of Jupiter and our moon. To differentiate these, while retaining this very physical concept, the criterion that a planet orbits the parent star, became a necessity.

And finally, comes the compulsion on a planet to be the "Monarch of all it surveys". It must have enough dynamical dominance in its own neighbourhood that it either accumulates all nearby matter in itself or scatters any significant matter out of its backyard. Matter that is in its backyard becomes negligible compared to its own mass.

One criterion, which looks at known parameters of solar system objects and which makes an assessment of the nature of dynamical dominance, was devised by Stern and Levision (2002) and elaborated upon by Steven Soter (2006). This parameter is defined in terms of the mass and orbital period of a solar system object as

$$\Lambda = \kappa M^2/P,$$

where, M is the mass of the solar system object, P is its orbital period, and κ is a constant. The parameter Λ is related to a characteristic timescale for scattering or ejection of matter from the neighbourhood of the scattering body.

A look at *Figure* 7 that places all the planets, the dwarf planets

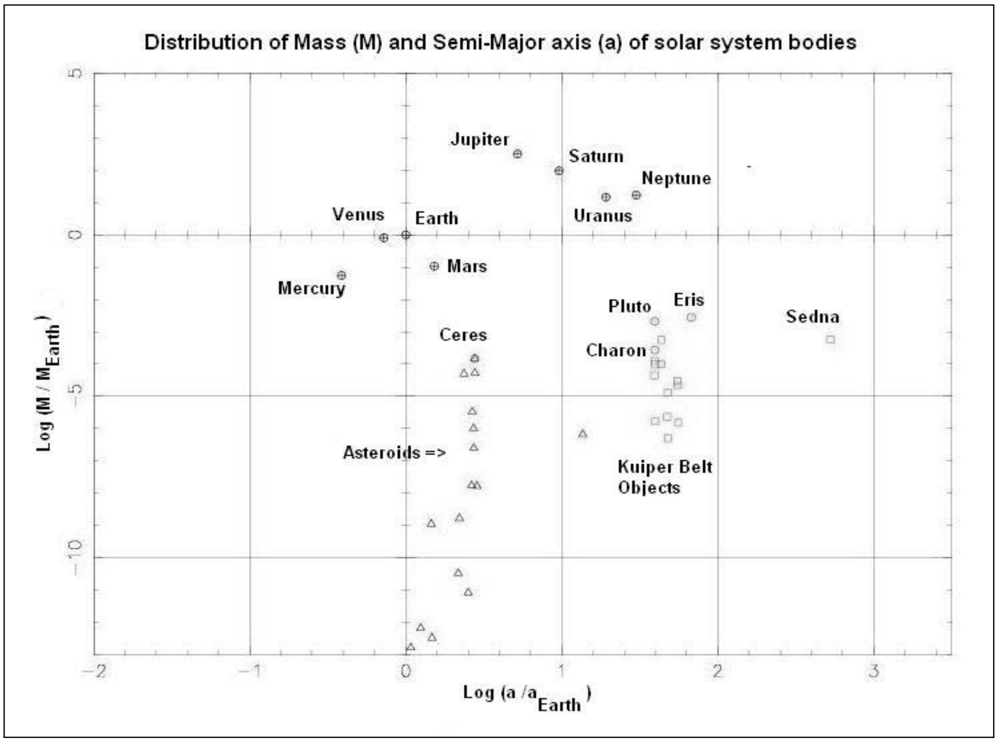

Figure 7. Mass versus Semi-Major axis for the major solar system objects.

and some asteroids and Kuiper belt[7] objects in a diagram showing the mass versus their orbital radius, clearly delineates the distinction in this physical characterization that exists between the eight classical planets and Pluto. All the eight classical planets have the parameter $\Lambda > 1$, while all other solar system objects fall in a region of the diagram with Λ much less than 1. This diagram however, does not distinguish so clearly between the dwarf planets and the other minor bodies of the solar system.

[7] **Kuiper belt:** A population of small icy bodies, similar in size to asteroids, occupying a ring-shaped region in the plane of the solar system extending from the orbit of Neptune (30 AU from the Sun) out to possibly 100 or 150 AU.

Astronomical Unit (AU): The mean distance between the Earth and the Sun. Its value is 149,597,870 km.

The new overview regarding the Solar System that is emerging from the studies of the larger minor bodies in Trans-Neptunian orbits and a study of their relation *vis-à-vis* Pluto, has been the understanding of ice dwarfs in the extreme outer regions of the solar system, as planetary embryos. The growth of these planetary embryos was limited at about 200-2,000 kms across in dimension. These are the preliminary planetary conglomerations from which the larger planets accumulated. The ice dwarfs would have retained the original compositions of these planetary accumulations, unlike the planets which would have gone through a period of evolution and possible differentiation. It is for this reason that a close study of these ice dwarfs of the solar system is a very essential task in our understanding of planetary formation.

Our understanding about this enduringly interesting celestial object – Pluto – is a fraction of a tip of the ice dwarf. The New Horizons spacecraft that was recently launched and has just whizzed past Jupiter, is on its way to Pluto, to give us an unprecedented wealth of information about this planet. The date of closest approach of the New Horizons spacecraft with Pluto is July 14, 2015. Let us mark this in our calendars and keep our date with Pluto.

Acknowledgements

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