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PREDICTION OF PLUTO BY V. B. KETAKAR

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After the discovery of Neptune in 1846, speculations about the existence of still further planets had begun. The work towards the prediction of trans-Naptunian planets was carried out by Astronomers like Todd[1], Forbes[2], Flammarian[3], Lau[4], Gaillot[5], See[6], Ketakar[7], Pickering[8] and Lowel[9]. Except Ketakar, all other astronomers had applied either one or both of the approaches given below:

(*i*) The positions of Neptune or Uranus at different instances are calculated by taking into consideration the gravitational effect of the Sun and also the gravitational perturbations of other known planets. The calculated results are then compared with the ones that have actually been observed for the planet under study. The difference, if any, is accounted for, in terms of the undiscovered heavenly bodies.

(*ii*) The aphelion distances of most of the periodic comets can be associated with one or the other known planet. Naturally the periodic comets having their aphelion distances, beyond the known planets give clue to the presence of some unknown planets.

Indian astronomer V. B. Ketakar believed in the existence of two planets beyond the orbit of Neptune. He predicted the positions and the orbital elements of these two planets by applying a radically different approach. Laplace's laws[10] of the satellites of Jupiter were modified and applied by Ketakar for arriving at the results. His predictions* about these planets were reported in the ***Bulletin of the Astronomical Society of France*** in May 1911 (p. 277).

For predicting the position (heliocentric longitude), daily mean motion, period and distance of Pluto Ketakar made use of the modified form of Laplace's laws given by the relations

*The comparison of the published results with those given in Ketakar's original documents reveal that the longitudes of the two planets in the Bulletin have been interchanged. When, why and where this change occurred is not known. It may also be added that the actual longitude of Pluto is found to be equal to the one that is given in Ketakar's original documents.

$$u-4n+3p=0 \quad \ldots \quad (1)$$
and $$U-4N+3P=180^\circ \quad \ldots \quad (2)$$

where u, n and p denote the daily mean motions of Uranus, Neptune and Pluto respectively while U, N and P denote their respective mean longitudes.

Substituting the known values of u and n as 42″.2309 and 21″.5350 respectively, Ketakar found the daily mean motion p to be 14″.6364. This value of daily mean motion gave the period of Pluto as 242.28 years. By applying Kepler's third law of motion, the distance of Pluto was found to be 38.95 A.U.

Using annare for the year 1911, Ketakar calculated that Uranus and Neptune were in exact opposition on July 23, 1911 and had longitudes of 289°-51′-52″ and 109°-51′-57″ respectively. Equation (2) gives that when Uranus and Neptune are in opposition, Pluto and Neptune will be in conjunction with each other. Therefore, the longitude of Pluto on July 23, 1911 ought to be equal to 109°-51′-57″. Applying the mean motion arrived at by Ketakar and assuming that it remains uniform, he found the longitude of Pluto to be 109°-2-′26′ on January 1, 1911.

Again by applying the relations

$$n-2p+v=0 \quad \ldots \quad (3)$$
and $$N-2P+V=180^\circ \quad \ldots \quad (4)$$

and proceeding exactly in the same way as adopted for Pluto, the values of mean motion, period, distance and longitude had been calculated for the trans-Plutonian planet. Here v and V denote respectively the mean motion and mean longitude for the trans-Plutonian planet. The positions and other orbital elements of two planets beyond the orbit of Neptune, as predicted by Ketakar, are given in Table 1.

TABLE 1

Ketakar's orbital elements of trans-Neptunian planets

Elements	1st planet (Brahmā)	2nd planet (Viṣṇu)
Mean longitude on July 23, 1911	109°-51′-57″	289°-51′-52″
Mean longitude on January 1, 1911	109°-2′-26″	289°-25′-42″
Mean distance (A.U.)	38.95	59.573
Daily mean motion	14″.6364	7″.7378
Period (years)	242.28	458.27

Again in the year 1912, Ketakar tabulated the eccentricity, period, inclination, perihelion and aphelion distances etc. of about 200 comets. This tabulation revealed to him that the aphelion distances of some of the periodic comets could be associated with the orbital radii of the planets. He also noted that there are few comets which have their aphelion distances slightly larger than the distance of the first trans-Neptunian planet predicted by him. As a result, his belief in the existence of a trans-Neptunian planet at a distance of 39-40 A.U. from the Sun became even stronger. He expresses this strong belief in a letter[11] dated April 15, 1912 addressed to Flammarian, Secretary, Astronomical Society of France.

Having dealt with Ketakar's method for finding the orbital elements of trans-Neptunian planets, we are posed with a number of questions regarding the accuracy of the results, the validity of the relations used, the circumstances which led him to use the particular equations etc.

It is known that out of all the astronomers who attempted for the prediction of Pluto, Pickering and Lowel are most renowned in the field. They made comprehensive calculations and assigned the values of complete set of orbital elements to the then hypothetical planet Pluto. Therefore, in order to judge the importance of the work done by Ketakar it would be worthwhile to compare his results with those of Pickering and Lowel and also with the ones which have been actually observed for Pluto.

Pickering predicted as many as seven hypothetical planets[12] beyond the orbits of Asteroids. He designated these planets by O, P, Q, R, S, T and U. The results for all these predictions were published in different years from 1909 to 1932. The orbital elements for all of Pickering's objects have been given in Table 2. We find from this table that O and P each has been ascribed three different sets of orbital elements. The longitudes of the nodes of the two O's differ by 80° and those for the two P's differ by a still larger angle of 142°.3. The calculations of the mean longitudes for the two O's on January 1, 1930 give their values as 104°.9 and 156°.9, which differ by a large angle of 51°.9. Again the periods and distances of the same planet (O or P) under different sets differ enormously from each other. Still astonishing are the distances of Q and R which place them at 875 and 6250 A.U. respectively. The thorough study of Pickering's objects given in Table 2 reveals that the results arrived at by him are really very funny. Anyhow, we have to make a choice of some set(s) for the purpose of comparing its values with those of Ketakar.

We find that the planets S, T and U cannot be selected for our purpose, because their derivations had been carried out after the actual discovery of Pluto. Also the distances given to the planets P's, Q and R are extremely large as compared to those of O's. Consequently our choice has been limited to the sets of O's. For convenience, the three O's of 1909[13], 1919[14] and 1928[15] may be called as O_1, O_2 and O_3 respectively.

TABLE 2

Pickering's planets

Elements	*O* 1909	*O* 1919	*O* 1928	*P* 1911	*P* 1928	*P* 1931	*Q* 1911	*R* 1911	*S* 1931	*T* 1931	*U* 1932
a Mean distance	51.9	55.1	30.1	123	67.7	75.5	875	6250	48.3	32.8	5.79
e Eccentricity		0.31	0.195	0.35	0.0	0.265	0.54	0.20			0.26
i Inclination		15° ± 5°		37°	30°.6	37°	86	26°			5°.[illegible]
n Mean annual motion	0°.964	0°.88		0°.338		0°.549	0°.029	0°.0008	1°.1		25°.84
P Periodic revolution (years)	373.5	409.1	164.8	1400	556.6	656	26000	500000	336	188	13.93
m Mass (Earth = 1)	2.0	2.0	0.5		20	49.6	20000	10000	5.3		0.045
M Magnitude	11.5-13.4	15	13.5		11	11.2	15.4	26	15		8.2
Ω Longitude of Node		100° ± 5°	180°	351°	208°.7	351°	93°	234°	271°		330°
$\bar{\omega}$ Longitude of Perihelion		280°.1	252°.5	160°		170°.5	105°	80°			1°.8
Perihelion date (years A.D.)		2129.1	1973.8			2398					1929.7
Heliocentric longitude on the dates of discovery	105°.8	95°.22	131°.4								

Pickering's object O_3 of 1928 can be left out because it is in fact not an exterior but a companion planet to Neptune. The distance (30.1 A.U.) and period (164.8 years) assigned to this object are nearly equal to those of Neptune. Out of the other two O's it seems difficult to make a choice. So we shall keep both these planets for the purpose of comparison.

Lowel[9] predicted a single planet with two sets of orbital elements having their positions 180° apart. The orbital elements corresponding to these two positions are given in Table 3. We find from this table that except the position, all other elements in the two sets have nearly the same values. So out of these two sets, we choose the one, with its position element closer to that of the observed value for Pluto.

TABLE 3

Elements of Lowel's X planet

Elements	1st position	2nd position
a Mean distance	43.0	44.7
e Eccentricity	0.202	0.195
m Mass (Earth = 1)	6.6592	7.5915
ϖ Longitude of Perihelion	203°.8	19°.6
l Heliocentric longitude on July 1, 1914	84°.8	262°.8
i Inclination	10° ±	10° ±
M Magnitude	12-13	12-13

There is no such difficulty with Ketakar's objects. He predicted only two planets at distances of 38.95 and 59.6 A.U. which he named as Brahmā and Viṣṇu respectively. It is very obvious that Brahmā corresponds to Pluto.

After having discussed all these, we give in Table 4 the values of the orbital elements of selected objects of Pickering, Lowel and Ketakar and also the values which have actually been observed for Pluto.

Regarding distance, period and daily mean motion we find that Ketakar's predictions are very nearly equal to the actually observed values of Pluto. While in the case of Lowel and Pickering, these differ very widely.

For comparing the longitudes due to different astronomers we adopt two methods given below:

(*i*) The longitudes of Pluto predicted by different astronomers have been brought to one and the same date, i.e. July 1, 1914 the time for which

TABLE 4

Orbital elements of Pluto by different astronomers

	Orbital Elements	Ketakar's Brahmā	Lowel's X	Pickering's O_1 of 1909	Pickering's O_2 on 1919	Observed values
a	Mean distance (A.U.)	38.95	43.0	51.9	55.1	39.52
e	Eccentricity	---	0.202	---	0.31	0.249
i	Inclination	---	10°	21°	15°	17°.15
Ω	Longitude of Node	--	---	---	100°	109°.1
$\bar{\omega}$	Longitude of Perihelion	--	204°.9	—	280°.1	222°.68
n	Mean daily motion	14″.6364	12″.5825	9″.5000	8″.6733	14″.28301
P	Period (years)	242.28	282	373.5	409.1	248.475
T	Perihelion date (A.D.)	--	1991.2	—	2129.1	1989.76
L	Heli. longitude on July 1, 1914	114°.23	84°.0	110°.6193	91°.3	113°.63
m	Mass (Earth = 1)	—	6.6	2.0	2.0	0.1

Lowel had given the longitude of Pluto. The calculations for this shift have been made by assuming that the motion of the planet is uniform and is equal to the mean motion derived by the concerned astronomer. These derived values have been given in Table 4. From this table we find again that Ketakar's value of the longitude is closest to the actual value of Pluto differing only by 0°.6. The next in accuracy falls Pickering's O of 1909 where the difference is found to be 3°.01; while Pickering's O of 1919 and Lowel's X differ from the actual value by large angles of 22°.33 and 29°.63 respectively.

(*ii*) Each astronomer had allotted some position to Pluto on a day, near about the time of his prediction. For comparing these results, the actual position of Pluto corresponding to these dates has been calculated and given in Table 5.

TABLE 5

Predicted positions of Pluto

Astronomer	Date	Predicted position	Observed position
Pickering's O_1	Jan. 1, 1909	105°.8	105°.59
Pickering's O_2	Jan. 1, 1919	95°.22	120°.22
Lowel's X	July 1, 1914	84°.0	113°.64
Ketakar's Brahmā	Jan. 1, 1911	109°.04	108°.52

We note that Pickering's *O* of 1909 and Ketakar's Brahmā have positions very nearly equal to the one that has actually been observed for Pluto differing only by 0°.21 and 0°.42 respectively. While Pickering's *O* of 1909 and Lowel's *X* differ enormously from the actual position.

So if judged either absolutely or in comparison with any other astronomer, the results arrived at by Ketakar are remarkably accurate.

Laplace's laws had been derived by Laplace for the three consecutive satellites namely I_0, Europa and Ganymede, which hold 2nd, 3rd and 4th positions in the order of their distance from Jupiter. These laws were verified by Delambre[16] and were found to hold good with remarkable accuracy. The derivation of these laws had been brought about by taking into consideration the principle of commensurability, the gravitational influence of Jupiter and also the mutual perturbations produced by these satellites. We know that the satellites move about their primaries in much the same way as the planets do around the Sun. Naturally these laws can also be applied for the planets of the solar system. The validity of these laws for the system of planets has been shown to be beyond any doubt by the results obtained by Ketakar for the prediction of Pluto.

From his original documents, it can be known that Ketakar wanted to ascribe the distance of 38-39 A.U. to Pluto. Now what made him assume the distance of Pluto to be near about this value is not at all clear. Probe in this direction reveals that he could not have been influenced by the earlier predictions because none gave a distance less than 44 A.U. for Pluto. Again the study of the relationships between distances or periods of various planets and also of the satellites of planets do not take us anywhere. Moreover, this method of Ketakar is unable to provide all the required elements of a planet.

From the discussions that we had so far, we know that Ketakar derived the values of less number of orbital elements. But the high accuracy with which the period, distance and position of Pluto had been predicted by him could not be obtained by any other astronomer.

It may also be emphasized that Brown[17], a renowned mathematician and Celestial Mechanician in Yale University in 1930 pointed out that gravitational perturbations on Neptune or Uranus due to Pluto is so small that on the basis of perturbation theory, one can not predict the existence or position of Pluto with any certainty[18]. Lowel himself admitted that when an unknown is so far removed relatively from the planet, it perturbs, precise prediction of its place does not seem to be possible. Therefore, we must regard the fact that the discovery of Pluto on the photographic plate was more a matter of chance. On the other hand, Ketakar's extension of the theory of satellites of Jupiter in the Solar system is justifiable.

After the discovery of Pluto in March, 1930, the astronomers of Lowel Observatory called it as Lowel's object, while Pickering called it as his own object *O*. The controversy existed for a few years. Finally, Pickering reconciled himself by saying that the planetary symbol P_L for Pluto stood for Pickering-Lowel. Ketakar could not participate in the controversy because for a few years before his death in August, 1930, he suffered from paralysis and even his tongue got affected. He was in such a critical state of health that he could not know anything about the scientific world. So he could not make any comment about the prediction of Pluto.

As regards the planet next to Pluto, we know that exhaustive calculations towards its prediction have been carried out by astronomers like Sevin[19], Strubell[20], Kritizinger[21] and Brady[22]. But in spite of these predictions and long search for it in heavens by various observers, such a heavenly body has not been traced so far. So it is not possible to decide whose prediction about this planet is more accurate. Anyhow, the latest astronomer to predict this planet is Brady. The orbital elements arrived at by him about this planet are given in Table 6.

TABLE 6

Position and other elements of Brady's object

	Elements	Value
m,	Mass of the Planet (Sun = 1)	0.0009
P,	Period (Years)	464
e,	Eccentricity	0.07
a,	Semi-major axis (A.U.)	59.94
i,	Inclination	120°
T,	Time of Perihelion passage	1635 A.D.
π	Longitude of Node	115°.75
$\tilde{\omega}$,	Longitude of Perihelion	181°

Comparison of Brady's predictions with that of Ketakar shows that the values of distance and period for the trans-Plutonian planet arrived at by Ketakar and Brady are very nearly equal. As regards the inclination of the orbit of this planet, Ketakar is silent, while Brady gives its value at 120°. This inclination shows that the motion is retrograde.

It may also be pointed out that Goldreich and Ward[23] concluded that the combination of large mass and unusual orbital inclination of Brady's object would have two serious effects on the Solar system. (*a*) The angle between the solar axis and the normal to the ecliptic would suffer large variations ($=2\pi$) with a period of a few times 10^7 years, and (*b*) the co-planer configuration of the outer solar system would be disrupted on a time scale of 10^6 years. As such, the unusual inclination of the orbit is not possible.

In the light of all this, we can say that regarding the prediction of Pluto and also the next planet, Ketakar's work is in no way less important than that of any other astronomer. Therefore, Ketakar must get due recognition not only for the best results but also for his simple and radically different treatment.

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