THE INFLUENCE OF DWARF PLANETS ON THE STABILITY OF OBJECTS IN THE KUIPER BELT

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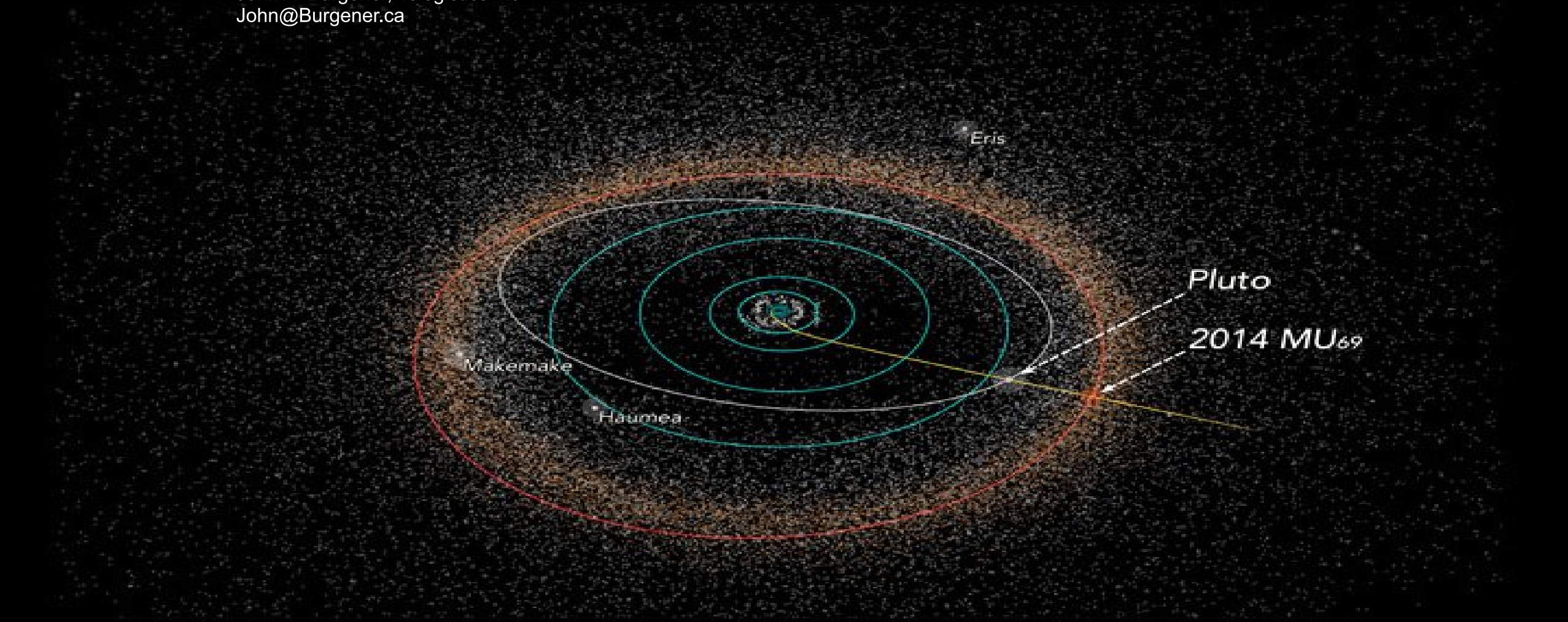


Origins of comets are generally considered to be
due to the influence of Jupiter, Saturn, Uranus, and Neptune,
primarily on the Scattered Disk of the Kuiper Belt.

For instance: Nesvorný et al,
“Origin and Evolution of Short-period Comets”, 2017

The Dwarf Planets should also be considered.

Origin and Evolution of Short-period Comets, Nesvorný et al, The Astrophysical Journal, 845:27 (25pp), 2017 August 10
https://doi.org/10.3847/1538-4357/aa7cf6

For close approaches to Kuiper Belt Objects (KBO),
Dwarf Planets have a stronger gravitational pull
than Neptune or Jupiter.

It is desirable to define a Zone of Influence (ZOI)
in which the gravitational pull of a Dwarf Planet
is at least 10 X greater than the pull of Jupiter or Neptune.

The orbits of the KBOs effected by such a ZOI
should be significantly changed,
and many will move into the inner Solar System
to become Short Period Comets.

To consider the influence of Dwarf Planets on Kuiper Belt Objects we need a good estimate of how many there are.

Smaller KBO are difficult to see and our estimates are not well defined.

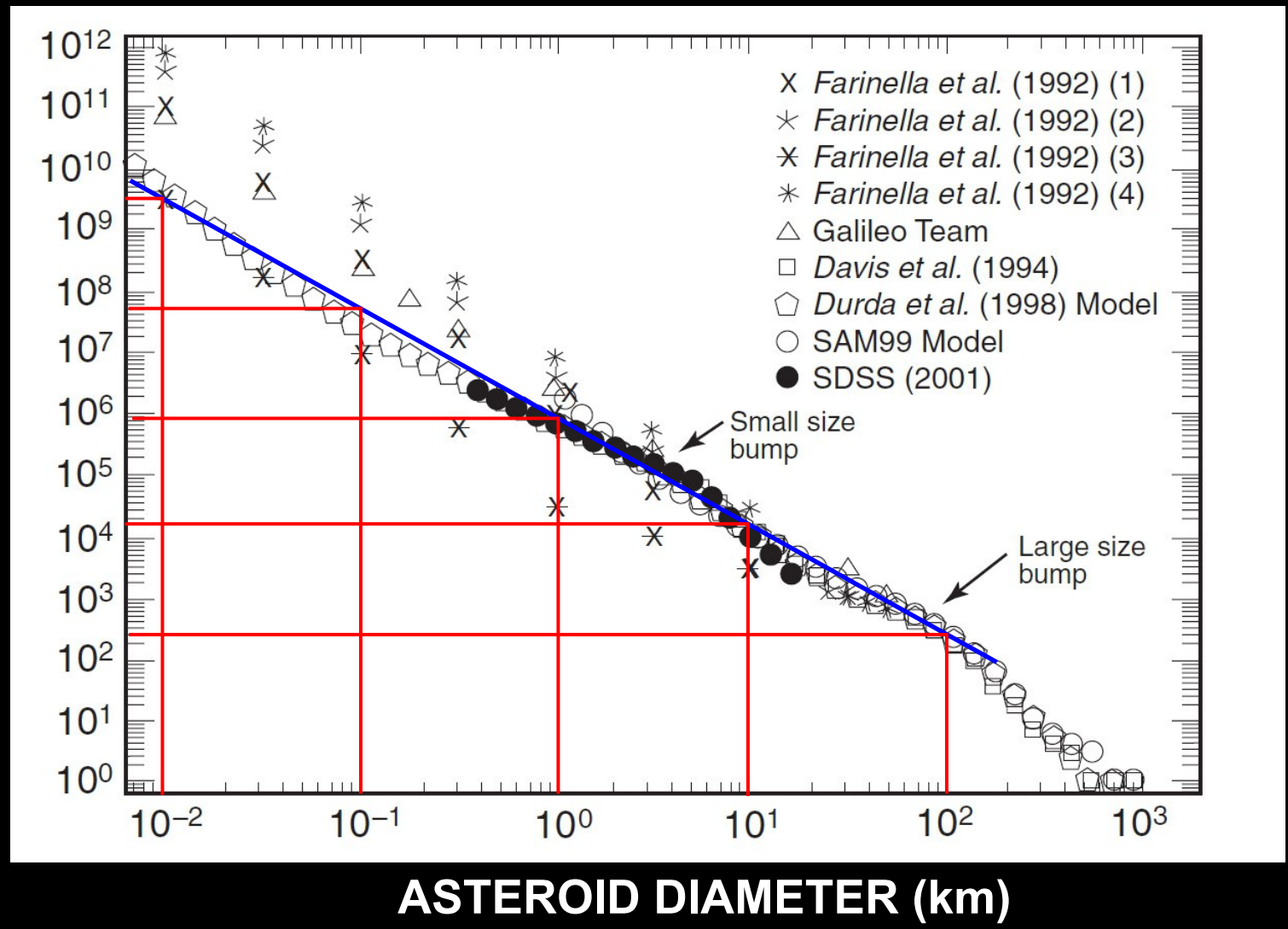
The asteroid belt is well studied, and populations of different sizes are well defined. It is reasonable to assume that the size distribution of KBO will be similar to the size distribution of asteroids.

As Asteroid size decreases 10X, population increases by ~ 10^1.77

Asteroid Diameter km	# Asteroids
0.01	4 X 10^9
0.1	6 X 10^7
1.0	1 X 10^6
10	1.7 X 10^4
100	3 X 10^2

number $\propto \Delta$ Size^1.77

Comparison of Asteroid size distribution: Observations and Models



Collisional Evolution of Small-Body Populations (pp. 545–558)
D. R. Davis, D. D. Durda, F. Marzari, A. Campo Bagatin, and R. Gil-Hutton, a chapter in "ASTEROIDS III", Edited by William Bottke, Alberto Cellino, Paolo Paolicchi, and Richard P. Binzel, University of Arizona Press, 2002.

KBO in Kuiper Belt & Size Distribution

Assume that the KBO population size distribution is similar to the Asteroids

Present estimates of numbers of objects in the Kuiper Belt:
~ 100,000 objects > 100 km **(Reference: Pitjev and Pitjev 2018)**

Size distribution is ~proportional to ∆r^1.77, so the size distribution will be:

100+ km	**100,000**
10+ km	**6,000,000**
1+ km	**350,000,000**

"Mass of the Kuiper Belt", Pitjeva, E.V. & Pitjev, N.P. Celestial Mechanics and Dynamical Astronomy (Sept. 2018) 130: 57. https://doi.org/10.1007/s10569-018-9853-5

Nesvorný et al 2017 estimate about 15 million 10Km size objects in the scattered disk,
so these numbers for the classical and resonate zones are appropriate.

Consider a KBO coming within the distance of a Dwarf Planet, eg Pluto, such that the Dwarf Planet's gravitational acceleration is 10X greater than the acceleration of Jupiter or Neptune.

$10 \text{ X } g_{Jupiter(48AU)} = 3.06X10\text{^-}11 \text{ km/s}^2$

Match 10 X Jupiter Acc to Pluto Acc:

$g_{Pluto} = GM_P/r_P^2 = 10 \text{ X } GM_J/r_J^2 = 3.06X10^{-11} \text{ km/s}^2$

$r_{Pluto} = 5{,}323{,}200 \text{ km}$

At 5,323,200 km, the pull of Pluto is 10 X greater than the pull of Jupiter

Gravity is a time dependant function.

Distance^2 and Time determine effect.

Jupiter's orbit is ~12 years, so assume 6 years of Jupiter's gravity has a significant effect on KBO orbits.

$\Delta v = g_{Jupiter}$ X 6 years = 3.06X10^-12 km/s ^{2} X 6 X 31,557,600 s

Δv = 5.794 X 10^-4 km/s

Δv = The change in speed of a KBO due to Jupiter's gravitational pull for 6 years.

Definition of the Zone of Interaction (ZOI):

The volume of space effected by a Dwarf Planet so that the Δv accumulated by a Kuiper Belt Object (KBO) is greater or equal to 10 X $\Delta v_{Jupiter\ @\ 48\ AU\ for\ 6\ years}$:

$\Delta v = 5.794 \text{ X } 10^{-3}$ km/s

Any combination of time and distance that provides this Δv will be in the ZOI.

For Pluto to match 10 X ∆v of Jupiter:

r(km)	r^2	Time (sec)	Time (Years)	Speed
5,323,200	2.83 E13	188,877,117	6.00	0.04 km/s
2,200,000	4.84 E12	32,261,098	1.02	0.10 km/s
1,400,000	1.96 E12	13,064,411	0.41	0.15 km/s
1,000,000	1.00 E12	6,665,516	0.21	0.21 km/s
420,000	1.76 E11	1,175,797	0.04	0.50 km/s
380,000	1.44 E11	962,501	0.03	0.55 km/s
156,000	2.43 E10	162,212	0.01	1.35 km/s
97,000	9.41 E09	62,716	0.00	2.17 km/s
45,000	2.02 E09	13,498	0.00	4.67 km/s

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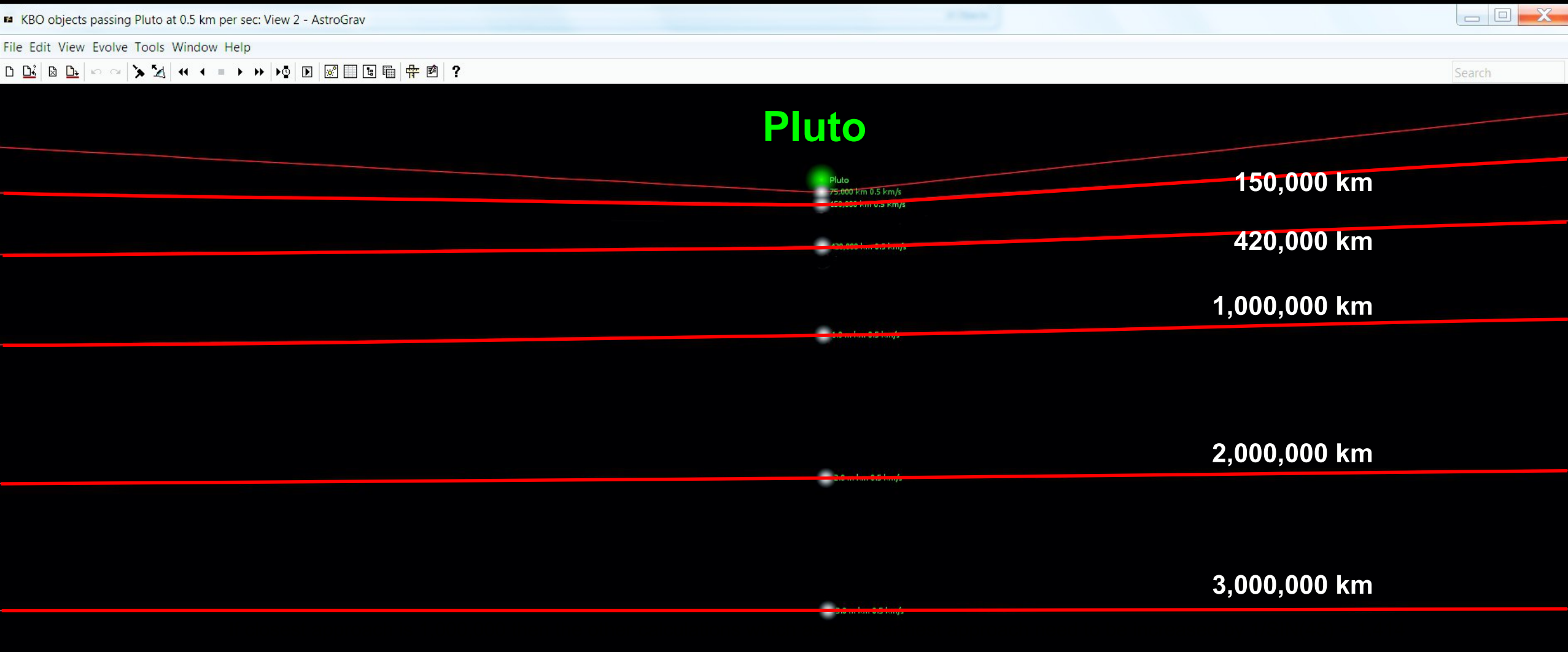
Orbit changes from close pass of Pluto at 0.5 km/s

Orbits drawn by AstroGrav (http://www.astrograv.co.uk)

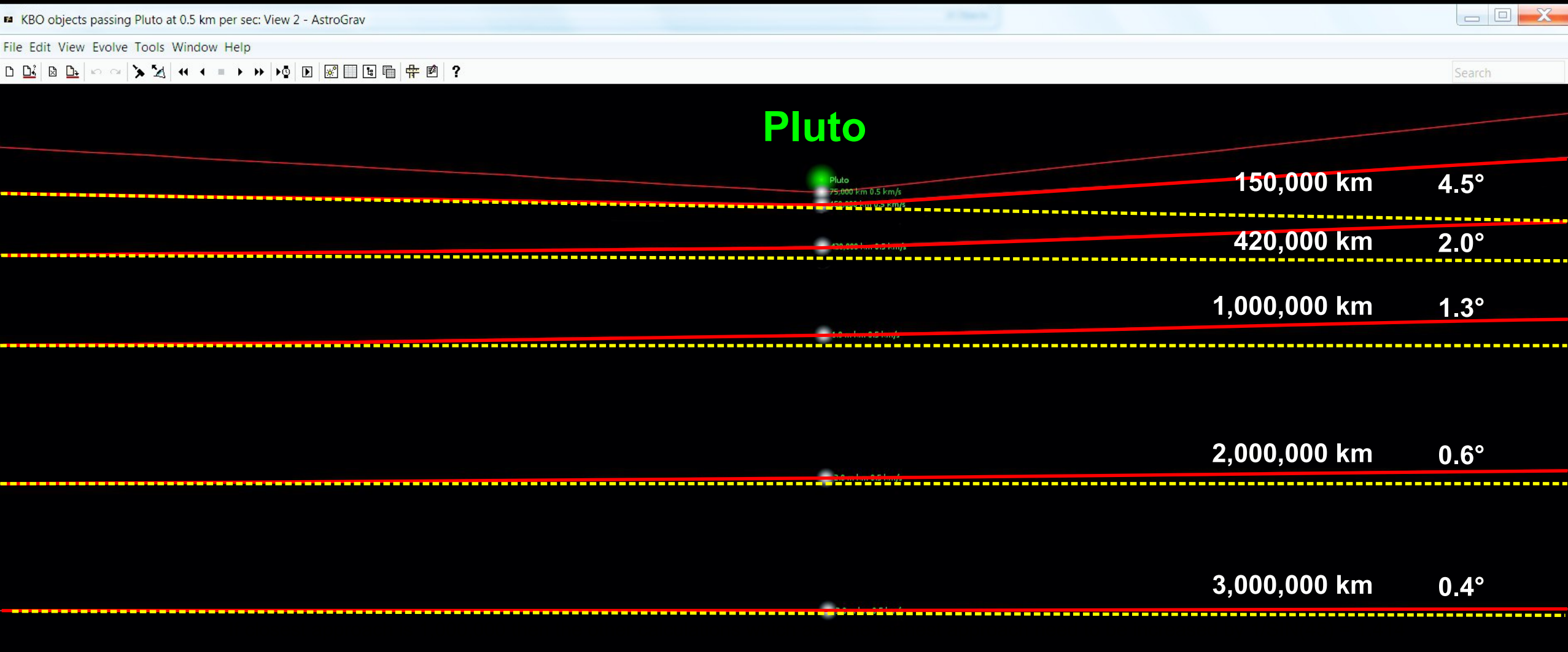


Orbit changes from close pass of Pluto at 0.5 km/s

(From AstroGrav)

Red Line = path with Pluto Influence

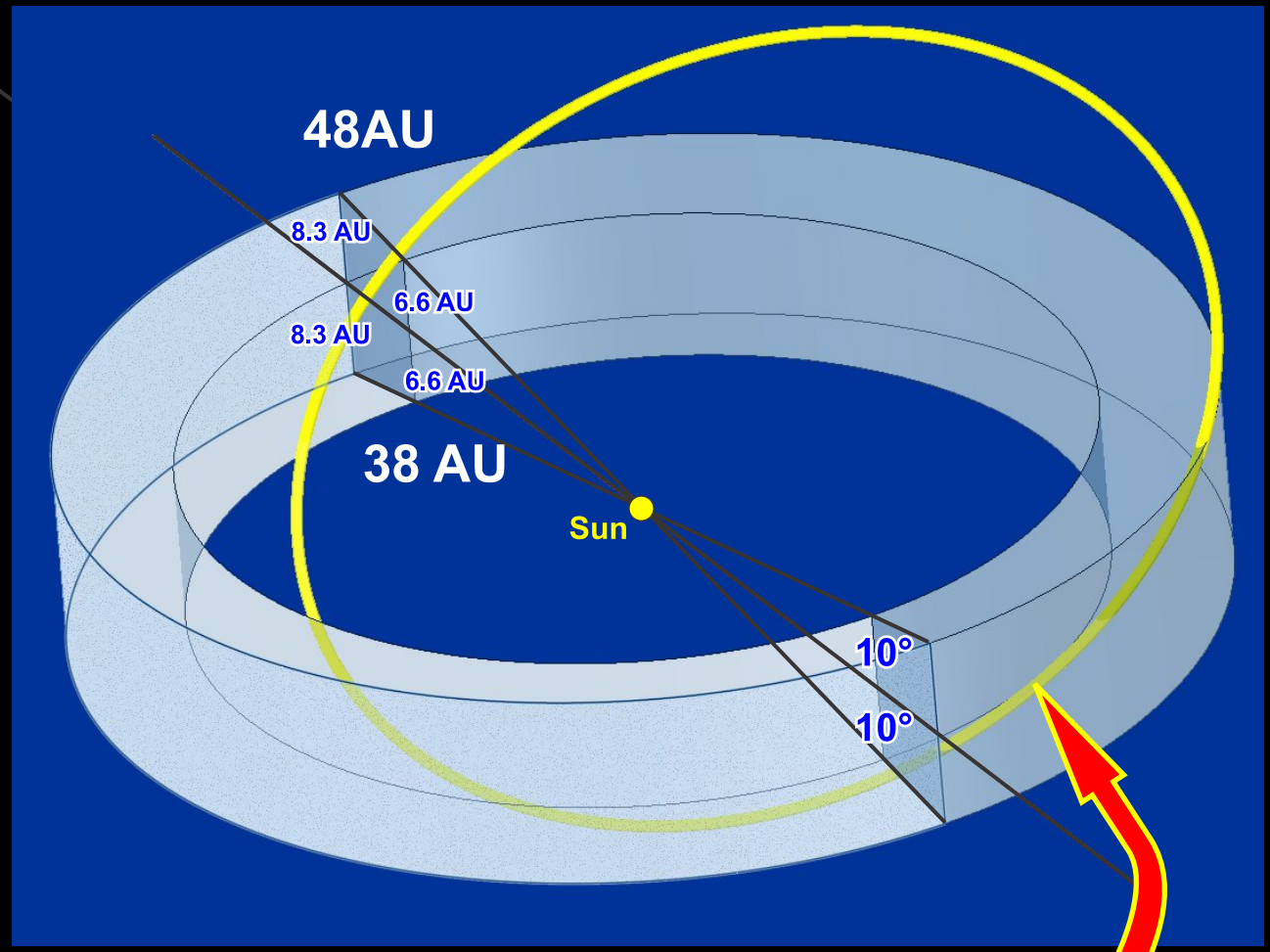
Yellow Line = path without Pluto Influence



Pluto's orbit

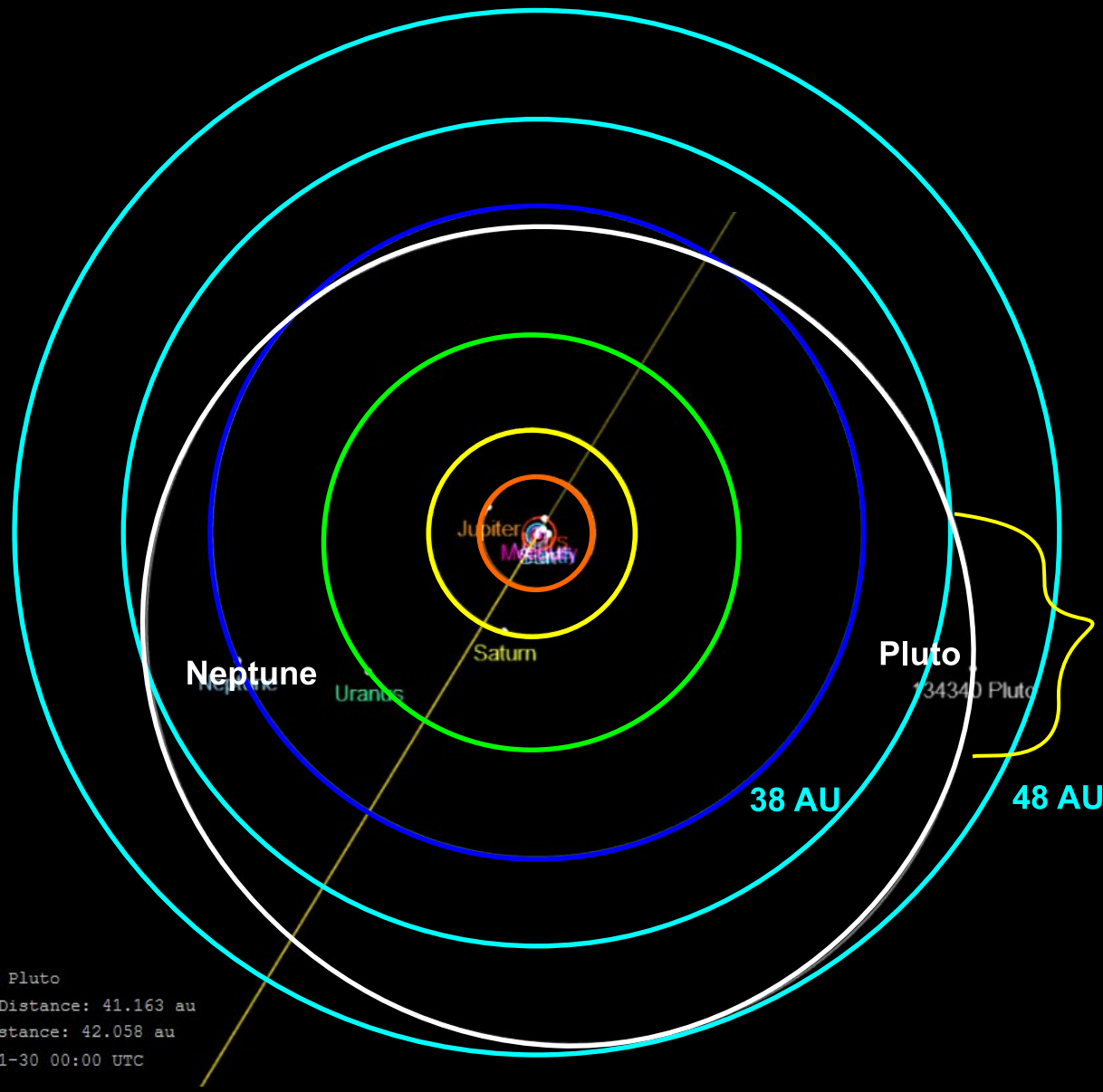
intersects the main KB zone
(includes classical and resonate zones)
for approx. 35 years,

ranging from 36 to 44 AU distance from Sun.



35 years in most densely populated part of KB

Pluto travels in the main KB Zone for approx. 35 years



Pluto in Classical KB Zone

Image from NASA JPL Small Body Database

Radius of Influence of Pluto's Path:

Pluto is inclined at 17°. KB main zone is +/- 10°

Range is from 17°-10° = 7° up to 17°

Horizontal speed difference is generally < 0.2 km/sec
Vertical difference ranges from 0.55 - 1.37 km/sec

From the 10 X ∆v Jupiter chart:
at speed of .55 km/s, Zone of Influence is 380,000 km radius
at speed of 1.365 km/s, Zone of Influence is 156,000 km radius.

For simplicity, use average of 200,000 km radius

Volume of Pluto's Path:

With the average of 200,000 km radius:

area of path = ¶ r^2 = 1.257E11 km^2

Pluto takes ~ 35 years to pass through classical portion of KB,

= 1.5E8 *35 = 5.25E9 km

Volume of Pluto Zone of Influence = 6.48 E20 km^3

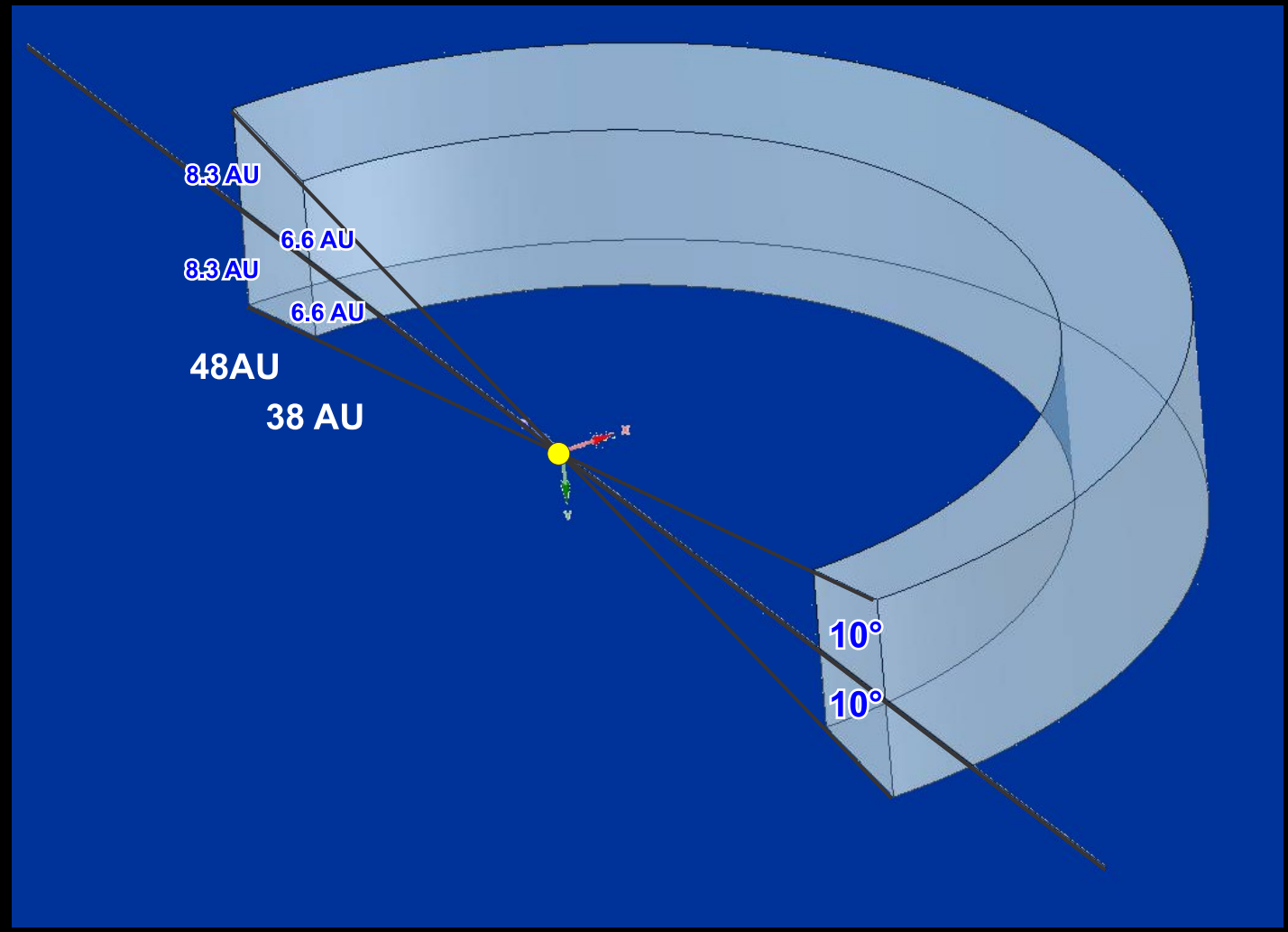
Classical & Resonant Kb

Volume of Kuiper Belt:

+/- 10 degrees, from 38 to 48 AU

Volume = 40,550 AU^3
Volume = 4.055E4 *1.49598E8^3 km^3

Volume = 1.3576 E29 km^3



Volume of cylinder = 3.14159 r^2 * h
= 3.14159 * 48 * 48 * 16.67 = 120,661
= 3.14159 * 38 * 38 * 13.19 = 59,835
Volume of cone 48 au = 1/3 Pi r^2 h = 40220
Volume of cone 38 au = 1/3 Pi r^2 h = 19945
Total Volume = (120,661 - 40,220) - (59,835 - 19,945) = 40,551 AU^3

Time required for Pluto to effect all of KB:

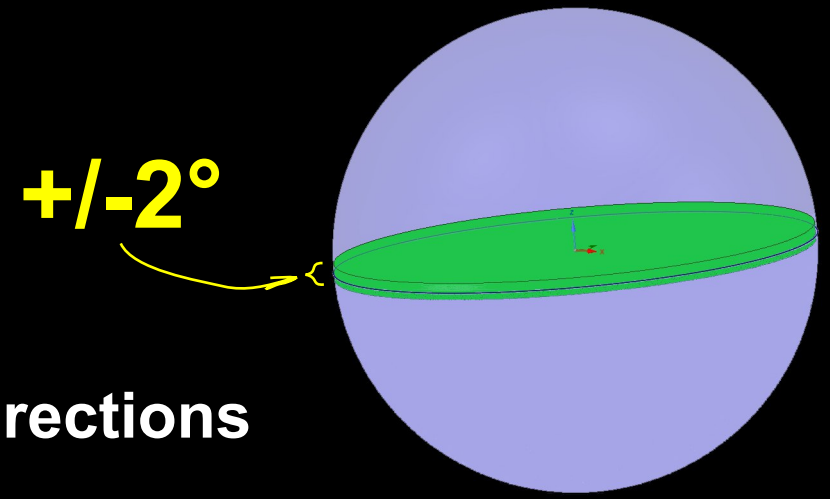
Volume of KB divided by Volume of Pluto ZOI

1.357E29 / 6.48E20 = 2.094 E8

= 209,400,000 orbits of 255 years each,

51,942,771,795 years to effect all of the Kuiper Belt

Pluto's Effect on KBOs



The effected KBOs orbit will change in random directions

Some away from the sun, some towards, some to the Scattered Disk.

The KBOs with a change parallel to the Ecliptic Plane
will have their Perihelion closer to the sun,
and move into the influence of the inner planets.

Parallel to the Ecliptic +/- 2 degrees can become Earth Crossing.

+/- 2 degrees is 2/90 or 1/45 of the effected KBOs.

How many KBOs will be effected?

6 million over 10 km diameter
350 million over 1 km diameter

51,942,771,795 years to effect all KB, divided by 6 million:

8,738 years per 10 km KBO effected
148 years per 1 km KBO effected

1 in 45 eventually cross Earth Orbit:

389,571 years between 10 km diameter comets in Earth crossing Orbit.
6,678 years between 1 km diameter comets in Earth crossing Orbit.

50000 Quaoar

Match 10 X Jupiter Acc to Quaoar Acc:

$g_{Quaoar} = GM_Q/r_Q^2 = GM_J/r_J^2 = 3.06X10^{-11}$ km/s ^{2}

$r_{Quaoar} = 1{,}746{,}893$ km

Quaoar travels between 42 and 45.2 AU so it does not effect ALL of the belt.

For Quaoar to match 10 X Jupiter ∆v:

r (km)	r^2	Time (sec)	Time (Years)	Speed
1,747,000	3.05E12	189,273,187	6.00	0.01 km/s
1,000,000	1.00E12	62,023,555	1.97	0.02 km/s
500,000	2.50E11	15,505,890	0.49	0.05 km/s
250,000	6.25E10	3,876,472	0.12	0.09 km/s
100,000	1.00E10	620,236	0.02	0.23 km/s
50,000	2.50E09	155,059	0.005	0.45 km/s
35,000	1.22E09	75,979	0.002	0.64 km/s
5,000	2.50E07	1,551	0.000	4.51 km/s

Radius of Influence Quaoar's Path:

Quaoar is inclined at 7.99°. KB Classical zone is +/- 10°

Relative Range is from 0° up to 8°

Horizontal speed difference is generally < 0.2 km/sec
Vertical difference ranges from 0.0 - 0.63 km/sec

From the 10 X ∆v Jupiter chart:
at speed of 0.1 km/s, Zone of Influence is 250,000 km radius
at speed of 0.63 km/s, Zone of Influence is 35,000 km radius.

For simplicity, use average of 100,000 km radius

Volume of Quaoar's Path:

With the average of 100,000 km radius:

area of path = ¶ r^2 = 3.14 E10 km^2

Quaoar remains in KB main zone for the entire 288 year orbit:

= 1.5E8 *288 = 4.10 E10 km length

Volume of Quaoar Zone of Influence = 1.287 E21 km^3

Time required for Quaoar to effect all of KB:

Volume of KB divided by Volume of Quaoar ZOI

1.357 E29 / 1.287 E21 = 1.05 E8

= 105,440,000 orbits of 288 years each,

30,366,400,000 years to effect all of the Kuiper Belt

How many KBOs will be effected by Quaoar?

6 million over 10 km diameter
350 million over 1 km diameter

30,369,125,000 years to effect all KBO, divided by 6 million:

5,062 years per 10 km object effected
87 years per 1 km object effected

1 in 45 eventually cross Earth Orbit:

227,800 years between 10 km diameter comets in Earth crossing Orbit.
3,900 years between 1 km diameter comets in Earth crossing Orbit.

Dwarf Planet	Mass	Inclination	Years in Classical KB	Max Speed Difference km/s	ZOI	Years per Earth Crossing 1 km KBO
Quaoar	1.40 E21	7.99°	288	0.63	1.29 E21	3,905
Pluto	1.30 E22	17.16°	35	1.38	6.48 E20	6,678
Eris	1.66 E22	44.04°	20	2.39	9.80 E19	99,343
Haumea	4.01 E21	28.19°	43	2.14	4.83 E19	102,698
MakeMake	4.40 E21	28.98°	25	2.14	2.74 E19	197,035
Orcus	6.41 E20	20.58°	34	1.67	2.56 E19	168,491
2002 Ms4	6.00 E20	17.68°	78	1.39	2.21 E19	212,472
Ixion	4.00 E20	19.59°	45	1.59	1.90 E19	229,583
Varuna	3.70 E20	17.20°	100	1.34	4.49 E18	1,094,026
Salacia	4.38 E20	23.93°	93	1.87	2.71 E18	1,747,027
2007 OR 10	1.75 E21	30.90°	0	1.87	0	

Dwarf Planet	ZOI	Years per Earth Crossing 1 km KBO	1 km Earth Crossing KBO / 10,000 years
Quaoar	1.29 E21	3,905	2.56
Pluto	6.48 E20	6,678	1.50
Eris	9.80 E19	99,343	0.10
Haumea	4.83 E19	102,698	0.10
MakeMake	2.74 E19	197,035	0.05
Orcus	2.56 E19	168,491	0.06
2002 Ms4	2.21 E19	212,472	0.05
Ixion	1.90 E19	229,583	0.04
Varuna	4.49 E18	1,094,026	0.01
Salacia	2.71 E18	1,747,027	0.01
		Total KBO / 10,000 years	4.47
		Years per new comet	2,236

Dwarf Planet	ZOI	Years per Earth Crossing 1 km KBO	1 km Earth Crossing KBO / 10,000 years	10 km Earth Crossing KBO per 1,000,000 years
Quaoar	1.29 E21	3,905	2.56	4.39
Pluto	6.48 E20	6,678	1.50	2.57
Eris	9.80 E19	99,343	0.10	0.17
Haumea	4.83 E19	102,698	0.10	0.17
MakeMake	2.74 E19	197,035	0.05	0.09
Orcus	2.56 E19	168,491	0.06	0.10
2002 Ms4	2.21 E19	212,472	0.05	0.08
Ixion	1.90 E19	229,583	0.04	0.07
Varuna	4.49 E18	1,094,026	0.01	0.02
Salacia	2.71 E18	1,747,027	0.01	0.01
		Total KBO / 10,000 years	4.47	
		Total KBO / 1,000,000 years		7.67
		Years per new comet	2,236	130,439

Dwarf Planet	ZOI	1 km Earth Crossing KBO per 10,000 years	10 km Earth Crossing KBO per 1,000,000 years	100 km Earth Crossing KBO per 100,000,000 years
Quaoar	1.29 E21	2.56	4.39	7.3
Pluto	6.48 E20	1.50	2.57	4.3
Eris	9.80 E19	0.10	0.17	0.3
Haumea	4.83 E19	0.10	0.17	0.3
MakeMake	2.74 E19	0.05	0.09	0.1
Orcus	2.56 E19	0.06	0.10	0.2
2002 Ms4	2.21 E19	0.05	0.08	0.1
Ixion	1.90 E19	0.04	0.07	0.1
Varuna	4.49 E18	0.01	0.02	0.0
Salacia	2.71 E18	0.01	0.01	0.0
Total KBO / 10,000 years		4.47		
Total KBO / 1,000,000 years			7.67	
Total KBO / 100,000,000 years				12.8
Years per new comet		2,236	130,439	7,826,337

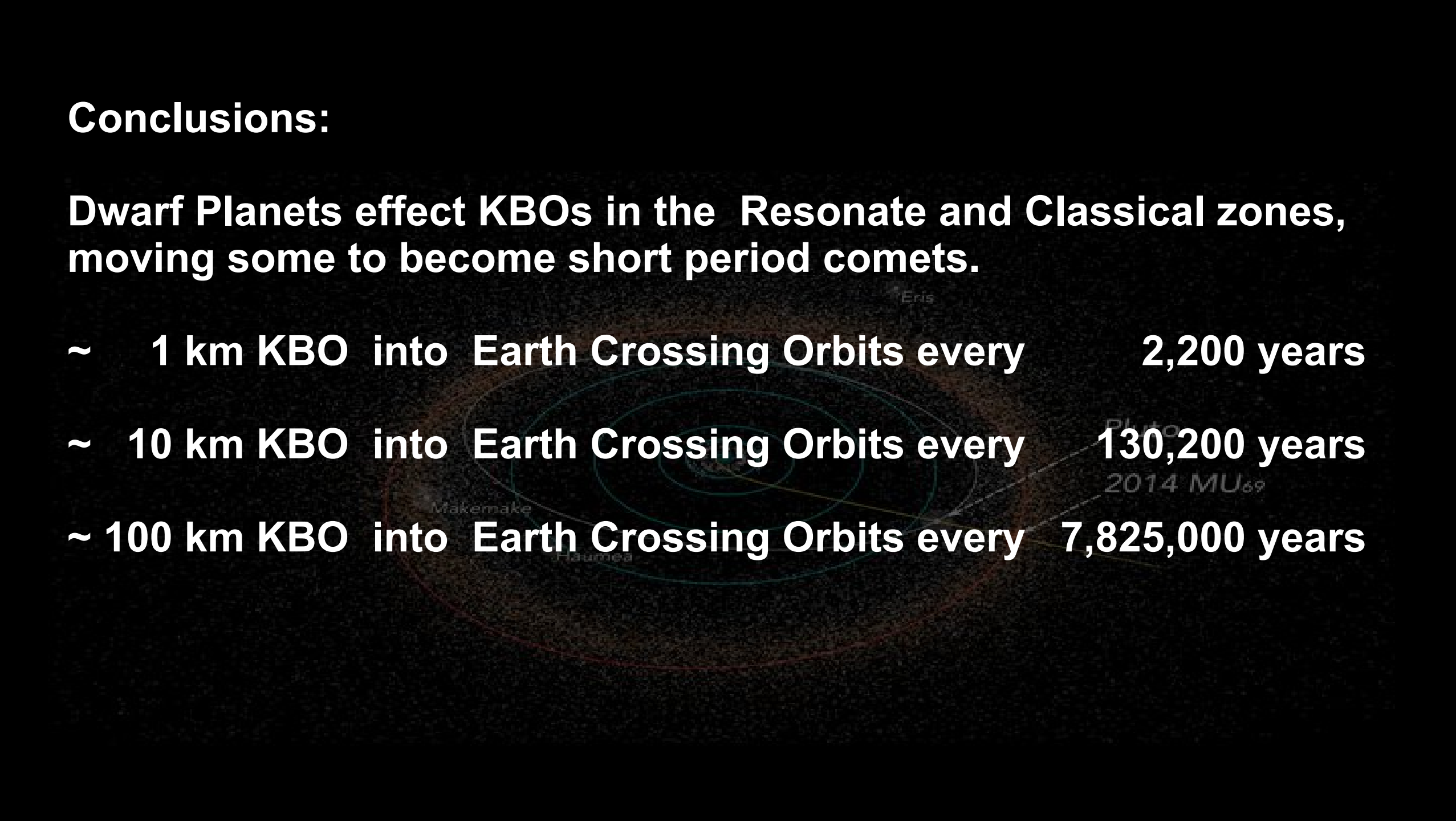
Conclusions:

Dwarf Planets effect KBOs in the Resonate and Classical zones, moving some to become short period comets.

~ 1 km KBO into Earth Crossing Orbits every 2,200 years

~ 10 km KBO into Earth Crossing Orbits every 130,200 years

~ 100 km KBO into Earth Crossing Orbits every 7,825,000 years



Conclusions:

If new 10 km KBOs go into Earth Crossing Orbit every 130,000 years, This implies that a 10 km impactor could not be an extinction event as such impacts should happen much more frequently than once every 100 million years.

While not all will impact Earth, a significant number should.

These frequencies are much higher than presently expected and warrant further study.

Conclusions:

**If new 10 km KBOs go into Earth Crossing Orbit every 130,000 years,
This implies that a 10 km impactor could not be an extinction event
as such impacts should happen much more frequently
than once every 100 million years.**

While not all will impact Earth, a significant number should.

**These frequencies are much higher than presently expected
and warrant further study.**

Musing on conditions at the beginning of the solar system:

1,000 X as many KBOs

+/- 5° for main zone instead of +/- 10°

Dwarf Planets in main zone of +/- 5°

Volume of KB Main zone: 20,368 AU^3 = 6.8187 E28 km^3

Pluto ZOI: +/- 2.5° max variation from KBOs
0.2 max vertical speed diff, near 0 min horizontal speed diff.
1 million km for 0.2, so go with 2 million as radius of ZOI
Quaoar ZOI: assume r = 500,000
Eris: same as Pluto: r = 2,000,000
etc.

Dwarf Planet	Mass	Inclination	Years in Classical KB	Max Speed Difference km/s	ZOI	10 km Earth Crossing KBO per 1,000,000 years
Quaoar	1.40 E21	2.5°	280	0.2	5.83 E21	40,712
Pluto	1.30 E22	2.5°	280	0.2	5.05 E23	3,526,556
Eris	1.66 E22	2.5°	280	0.2	8.02 E23	5,723,716
Haumea	4.01 E21	2.5°	280	0.2	4.77 E22	333,337
MakeMake	4.40 E21	2.5°	280	0.2	5.76 E22	402,131
Orcus	6.41 E20	2.5°	280	0.2	1.22 E21	8,534
2002 Ms4	6.00 E20	2.5°	280	0.2	1.07 E21	7,478
Ixion	4.00 E20	2.5°	280	0.2	4.76 E21	3,323
Varuna	3.70 E20	2.5°	280	0.2	4.07 E20	2,844
Salacia	4.38 E20	2.5°	280	0.2	5.71 E20	3,985
2007 OR 10	1.75 E21	2.5°	280	0.2	9.11 E21	63,612
				Total KBO / 1 million years		10,116,227
				# 10 km comets per year		10.1
				% of KBOs removed per million years		0.17 %

Dwarf Planet	10 km Earth Crossing KBO per 1,000,000 years
Quaoar	40,712
Pluto	3,526,556
Eris	5,723,716
Haumea	333,337
MakeMake	402,131
Orcus	8,534
2002 Ms4	7,478
Ixion	3,323
Varuna	2,844
Salacia	3,985
2007 OR 10	63,612
	10,116,227
	10.1
	0.17 %

Total KBO / 1 million years

10 km comets per year

% of KBOs removed per million years

Attrition rate
0.17% / million years

Time	% removed
1 billion years	83%
2 billion years	98%
3 billion years	99.5%
4 billion years	99.92%