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Using Ground-Based Small Telescopes in Solving Orbits of some Asteroids

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Abstract
This study demonstrates that small telescopes can be used to solve the orbits of bright asteroids. A 5-inch apochromatic refractor telescope located in Al-Khatim Observatory, in the desert of Abu Dhabi, United Arab Emirates, was used to determine these orbits. The observatory's MPC code is M44.

To validate the accuracy of our observations, we observed two asteroids with solved orbits published in the Minor Planet Center website on the basis of numerous observations: 99942 Apophis from Aten and PHA groups and 1036 Ganymed from Amor group.

The orbital element sets of both asteroids were identical. The maximum errors were 0.2% for Ganymed and 0.1% for Apophis, respectively. For equatorial coordinates generated by both sets, the difference in Apophis was less than one arc minute and that in Ganymed was less than 2 arcseconds. A small telescope with satisfactory guiding accuracy can be employed to obtain accurate orbital elements for bright asteroids.

Keywords:
Image processing, Apophis, Ganymed, Al-Khatim Observatory

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1. Introduction

Observing asteroids is a topic of considerable interest in the astronomical community because observing these objects is crucial to determine the orbits of newly discovered bodies. Moreover, continuous observations of the NEOs is critical to refine their orbits and detect any changes due to gravitational perturbations from massive bodies present in the solar system. Through small and medium telescopes, relatively bright asteroids can be monitored to determine their precise coordinates. In this study, we will demonstrate the accuracy that small observatories can provide in these important observations.

The six parameters that describe the osculating orbit of an asteroid for a given epoch are called Keplerian elements or orbital elements (Figure 1). This study compared the accuracy of orbital elements of some asteroids determined through small telescope observations with that published by MPC. Two elements determine the shape and size of the ellipse:

- Eccentricity (e): It represents the ellipse's shape, indicating how much it is elongated in comparison with a circle.
- Semimajor axis (a): It represents the sum of perihelion and aphelion distances divided by 2.

The orientation of an orbital plane in which the ellipse is embedded is based on two elements:

- Inclination (i): It refers to the ellipse's vertical tilt in relation to the reference plane, which is measured at the ascending node (wherein the orbit passes upward through the reference plane). Then, the tilt angle is measured perpendicular to the intersection line between the orbital and reference planes.
- Longitude of the ascending node (Ω): This line horizontally orients the ascending node of the ellipse (wherein the orbit passes upward through the reference plane, which is symbolized by Ω in relation to the vernal point of the reference frame (symbolized by Υ).

The remaining two elements are as follows:

- Argument of perihelion (ω) is defined as the ellipse's orientation in the orbital plane, and the angle is measured from the ascending to perihelion point.
- Mean anomaly (M) indicates the point at which the asteroid is in its orbital path. The mean anomaly ranges from 0° to 360° and is referenced to the perihelion point. If the asteroid were at the perihelion, the mean anomaly would be 0.

In addition to the above elements, the following parameters are usually listed:

- P (years): Orbital period of the asteroid.
- q (AU): Perihelion distance. This indicates the minimum distance between the asteroid and the Sun.
- MOID (AU): Minimum orbit intersection distance. This indicates the minimum distance between the asteroid and the Earth.
- H (mag.): Absolute magnitude.
- G: Magnitude slope parameter. Where the parameters H and G are used to compute the apparent magnitude of the asteroid.
- Epoch: The epoch of osculation of orbital elements.

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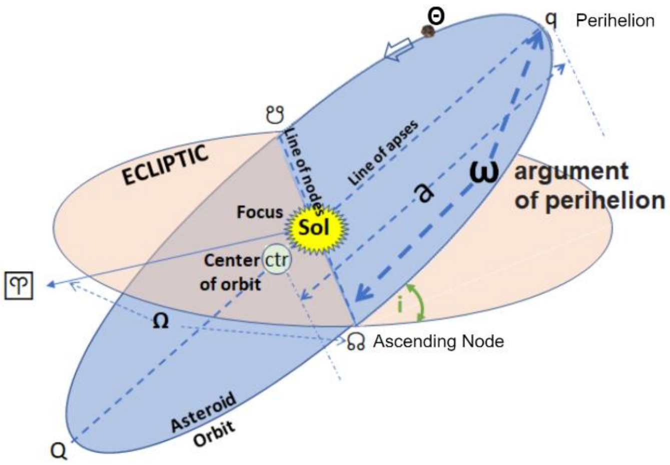

Figure 1: Orbital Elements (JimODell 2018)

NEOs are comets and asteroids that enter the Earth's neighborhood. By convention, a solar system body is a NEO if its closest approach to the Sun is less than 1.3 astronomical units (JPL 2021). NEOs are divided into several groups:

NECs: Near-Earth Comets: $q < 1.3$ au and $P < 200$ years.

NEAs: Near-Earth Asteroids $q < 1.3$ au.

Atiras: NEAs whose orbits are contained entirely with the orbit of the Earth: $a < 1.0$ au and $Q < 0.983$au.

Atens: Earth-crossing NEAs with semi-major axes smaller than Earth's: $a < 1.0$ au and $Q > 0.983$ au.

Apollos: Earth-crossing NEAs with semi-major axes that is larger than Earth's: $a > 1.0$ au and $q < 1.017$

Amors: Earth-approaching NEAs with orbits that is exterior to Earth's but is interior to Mars: $a > 1.0$ au and $1.017 < q < 1.3$au.

PHAs (Potentially Hazardous Asteroids): NEAs whose minimum orbit intersection distance with the Earth is ≤ 0.05 au and whose absolute magnitude (H) is brighter than or equals 22.0. MOID ≤ 0.05 au and $H \leq 22.0$.

2. Methods

To achieve our purpose, we used a refractor telescope, a 952-mm focal length, and f/7.5 focal ratio (Figure 2).

Camera: QHY163C Cooled CMOS camera, sensor: 4/3-inch 16-megapixel CMOS, effective pixel: 4656 × 3522, pixel size: 3.8 µm, and effective area: 17.7×13.4 mm. The pixel scale of our setup was 0.82"/pixel; however, the actual value was 1.65 "/pixel because our observations were performed using BIN 2.

Mount: CGX equatorial mount. Heavy duty belt-drive system minimizes backlash while providing smooth motor operation under heavy loads, controlled by CPWI Telescope Control Software.

Guider telescope and camera.

Automation software to automate the imaging sequence and control all the equipment.

Because of increased attention on NEA groups, we selected two asteroids of these groups, which were high in the sky at the time of our observations, and they were brighter than one magnitude than our limiting magnitude, which is between 16 and 17. The selected asteroids were (1036 Ganymed) from Amor group and (99942 Apophis) from Aten and PHA groups.

The first observation was performed on February 11, 2021, and the final observation was performed on March 24, 2021. Each asteroid was observed three times on each night separated by approximately 15 minutes, and the exposure time was 3 minutes. After images were obtained, Astrometrica (Raab 2018)

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was used to analyze images to obtain the coordinates of the asteroid in J2000.0.

Figure 2: Equipment Used to Perform Observations

3. Results

The asteroid 99942 Apophis (Figure 3) is presented inside the circle. Its coordinates can be accurately obtained from its relative position between field stars, and the star catalogue used was Gaia DR2.

Based on observations and image analysis performed using Astrometrica software, we obtained the coordinates of two asteroids on different nights. The time of observations was obtained from the header of the photos, which is read from Windows time. To ensure the accuracy of the time, synchronization was performed every 30 minutes with one of the time servers. Tables 1 and 2 list the coordinates of 1036 Ganymed and asteroid (99942 Apophis), respectively.

Table 1: 1036 Ganymed

Asteroid#	UTC Date	R.A. (J2000.0)	DEC. (J2000.0)	Magnitude
01036	C2021 02 11.73568	06 13 38.19	-11 48 51.3	13.6
01036	C2021 02 11.74828	06 13 38.00	-11 48 44.0	13.6
01036	C2021 02 11.76296	06 13 37.79	-11 48 35.5	13.6
01036	C2021 02 12.76647	06 13 25.81	-11 38 50.7	13.5

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01036	C2021 02 12.77697	06 13 25.68	-11 38 44.8	13.5
01036	C2021 02 12.78537	06 13 25.58	-11 38 39.7	13.5
01036	C2021 02 17.66839	06 12 51.37	-10 50 51.6	13.8
01036	C2021 02 17.67889	06 12 51.32	-10 50 45.3	13.8
01036	C2021 02 17.69706	06 12 51.23	-10 50 34.6	13.8
01036	C2021 02 18.67472	06 12 49.06	-10 40 58.2	13.7
01036	C2021 02 18.68586	06 12 49.02	-10 40 51.9	13.7
01036	C2021 02 18.69425	06 12 49.00	-10 40 46.6	13.7
01036	C2021 03 02.70159	06 14 19.56	-08 44 23.0	13.9
01036	C2021 03 02.71449	06 14 19.75	-08 44 15.9	13.9
01036	C2021 03 02.73273	06 14 20.02	-08 44 05.5	14.0
01036	C2021 03 05.67384	06 15 13.10	-08 16 31.8	14.0
01036	C2021 03 05.68451	06 15 13.29	-08 16 25.8	14.0
01036	C2021 03 05.70041	06 15 13.59	-08 16 17.0	13.9
01036	C2021 03 06.68287	06 15 33.84	-08 07 11.5	14.4
01036	C2021 03 06.69398	06 15 34.07	-08 07 05.1	14.4
01036	C2021 03 06.70795	06 15 34.34	-08 06 57.6	14.3
01036	C2021 03 07.68404	06 15 55.70	-07 57 59.6	14.3
01036	C2021 03 07.69486	06 15 55.93	-07 57 53.5	14.2
01036	C2021 03 07.70877	06 15 56.23	-07 57 46.0	14.3
01036	C2021 03 08.75059	06 16 20.29	-07 48 16.2	14.2
01036	C2021 03 08.76127	06 16 20.54	-07 48 10.5	14.2
01036	C2021 03 08.77499	06 16 20.84	-07 48 03.0	14.2
01036	C2021 03 09.75752	06 16 44.85	-07 39 10.2	14.3
01036	C2021 03 09.76822	06 16 45.11	-07 39 04.4	14.2
01036	C2021 03 09.77985	06 16 45.38	-07 38 58.0	14.3
01036	C2021 03 10.75541	06 17 10.41	-07 30 13.2	14.3
01036	C2021 03 10.76609	06 17 10.67	-07 30 07.8	14.3
01036	C2021 03 10.77770	06 17 10.97	-07 30 01.2	14.4
01036	C2021 03 11.68797	06 17 35.44	-07 21 55.9	14.2
01036	C2021 03 11.69881	06 17 35.72	-07 21 50.2	14.3
01036	C2021 03 11.71068	06 17 36.03	-07 21 43.8	14.3
01036	C2021 03 15.75681	06 19 35.88	-06 46 34.7	14.3
01036	C2021 03 15.76764	06 19 36.21	-06 46 29.2	14.3
01036	C2021 03 15.77953	06 19 36.51	-06 46 25.0	14.0
01036	C2021 03 18.71275	06 21 14.88	-06 21 48.9	14.5
01036	C2021 03 18.72148	06 21 15.18	-06 21 44.6	14.4
01036	C2021 03 18.73534	06 21 15.66	-06 21 37.6	14.6
01036	C2021 03 19.75123	06 21 51.78	-06 13 18.4	14.3
01036	C2021 03 19.76190	06 21 52.12	-06 13 12.9	14.4

01036	C2021 03 19.77367	06 21 52.54	-06 13 07.2	14.2
01036	C2021 03 20.72064	06 22 27.22	-06 05 27.2	14.2
01036	C2021 03 20.72920	06 22 27.54	-06 05 23.0	14.3
01036	C2021 03 20.74307	06 22 28.05	-06 05 16.0	14.5
01036	C2021 03 21.68880	06 23 03.58	-05 57 42.2	14.6
01036	C2021 03 21.69752	06 23 03.91	-05 57 38.0	14.5
01036	C2021 03 21.71142	06 23 04.42	-05 57 31.4	14.5
01036	C2021 03 22.66328	06 23 41.10	-05 49 59.7	14.4
01036	C2021 03 22.67186	06 23 41.41	-05 49 55.7	14.5
01036	C2021 03 22.68579	06 23 41.94	-05 49 49.1	14.4
01036	C2021 03 24.72192	06 25 03.13	-05 34 01.2	14.5
01036	C2021 03 24.73277	06 25 03.58	-05 33 56.5	14.5
01036	C2021 03 24.74451	06 25 04.03	-05 33 51.3	14.3

Table 2: 99942 Apophis

Asteroid#	UTC Date	R.A. (J2000.0)	DEC. (J2000.0)	Magnitude
99942	C2021 02 14.77648	10 51 42.01	-18 18 24.6	15.4
99942	C2021 02 14.79117	10 51 38.48	-18 18 11.2	15.1
99942	C2021 02 14.80319	10 51 35.55	-18 18 00.7	15.3
99942	C2021 02 15.81559	10 47 45.85	-18 01 15.4	15.6
99942	C2021 02 15.82609	10 47 43.17	-18 01 04.8	15.8
99942	C2021 02 15.84215	10 47 39.06	-18 00 47.9	15.5
99942	C2021 02 16.73347	10 44 12.95	-17 44 15.2	14.8
99942	C2021 02 16.74606	10 44 09.73	-17 44 02.6	14.9
99942	C2021 02 16.75236	10 44 08.18	-17 43 57.3	15.0
99942	C2021 02 17.78212	10 39 59.49	-17 23 03.7	15.6
99942	C2021 02 17.79608	10 39 55.89	-17 22 49.3	15.6
99942	C2021 02 17.81002	10 39 52.04	-17 22 32.2	15.6
99942	C2021 02 19.82493	10 31 25.75	-16 35 31.9	15.3
99942	C2021 02 19.83751	10 31 22.10	-16 35 13.7	15.5
99942	C2021 02 19.85221	10 31 17.93	-16 34 51.1	15.3
99942	C2021 03 07.75377	09 19 14.76	-06 15 50.5	15.3
99942	C2021 03 07.75678	09 19 13.88	-06 15 41.8	15.3
99942	C2021 03 07.76082	09 19 12.74	-06 15 29.9	15.2
99942	C2021 03 08.73072	09 15 08.30	-05 28 35.2	14.9
99942	C2021 03 08.74226	09 15 05.08	-05 28 01.7	14.9
99942	C2021 03 08.74539	09 15 04.21	-05 27 51.8	14.9

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99942	C2021 03 09.73016	09 11 01.72	-04 39 58.8	15.3
99942	C2021 03 09.73914	09 10 59.34	-04 39 32.9	15.3
99942	C2021 03 09.75168	09 10 55.91	-04 38 56.4	15.3
99942	C2021 03 10.72793	09 07 02.49	-03 51 21.4	15.3
99942	C2021 03 10.73825	09 06 59.70	-03 50 51.2	15.1
99942	C2021 03 10.74954	09 06 56.72	-03 50 17.3	15.5
99942	C2021 03 11.71623	09 03 12.73	-03 03 11.3	15.3
99942	C2021 03 11.72515	09 03 10.53	-03 02 46.3	15.3
99942	C2021 03 11.73826	09 03 07.25	-03 02 08.9	15.7
99942	C2021 03 15.78456	08 48 45.46	+00 11 51.0	14.9
99942	C2021 03 15.79334	08 48 43.44	+00 12 15.5	14.8
99942	C2021 03 15.80575	08 48 40.61	+00 12 49.6	15.0
99942	C2021 03 19.77846	08 36 50.67	+03 13 26.3	15.7
99942	C2021 03 19.78894	08 36 48.63	+03 13 54.2	15.5
99942	C2021 03 19.80007	08 36 46.57	+03 14 23.2	15.5
99942	C2021 03 20.74876	08 34 17.91	+03 55 32.7	15.2
99942	C2021 03 20.75778	08 34 16.34	+03 55 56.4	15.4
99942	C2021 03 20.77035	08 34 13.97	+03 56 29.3	15.7
99942	C2021 03 21.71650	08 31 53.42	+04 36 40.4	16.2
99942	C2021 03 21.72581	08 31 51.79	+04 37 04.6	16.1
99942	C2021 03 21.73850	08 31 49.60	+04 37 35.5	16.0
99942	C2021 03 22.69132	08 29 35.16	+05 17 14.8	16.0
99942	C2021 03 22.69854	08 29 33.90	+05 17 32.0	15.3
99942	C2021 03 22.71558	08 29 31.16	+05 18 12.7	15.8

where

- Asteroid#: The IAU asteroid number.
- UTC Date: The UT date and time at the middle time of the image.
- R.A. (J2000.0): The right ascension of the asteroid at the observation time for equinox 2000.0.
- Dec. (J2000.0): The declination of the asteroid at the observation time for equinox 2000.0.
- Magnitude: The apparent magnitude of the asteroid.

After obtaining the coordinates of the two asteroids, we fed them to a dedicated software to obtain asteroids' orbital elements based on our observations. We employed Find_Orb (Gray 2019) to obtain orbital elements. Table 3 lists the obtained orbital elements for both asteroids.

4. Discussion

To evaluate the accuracy of the obtained orbital elements, we compared them with those generated by the MPC website. Two orbital element sets were obtained for the asteroid 1036 Ganymed (Table 4):

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the first set was from MPC website and the second set was obtained from our observation. The last column presents the percentage error for each element. Table 5 shows the same results for the asteroids.

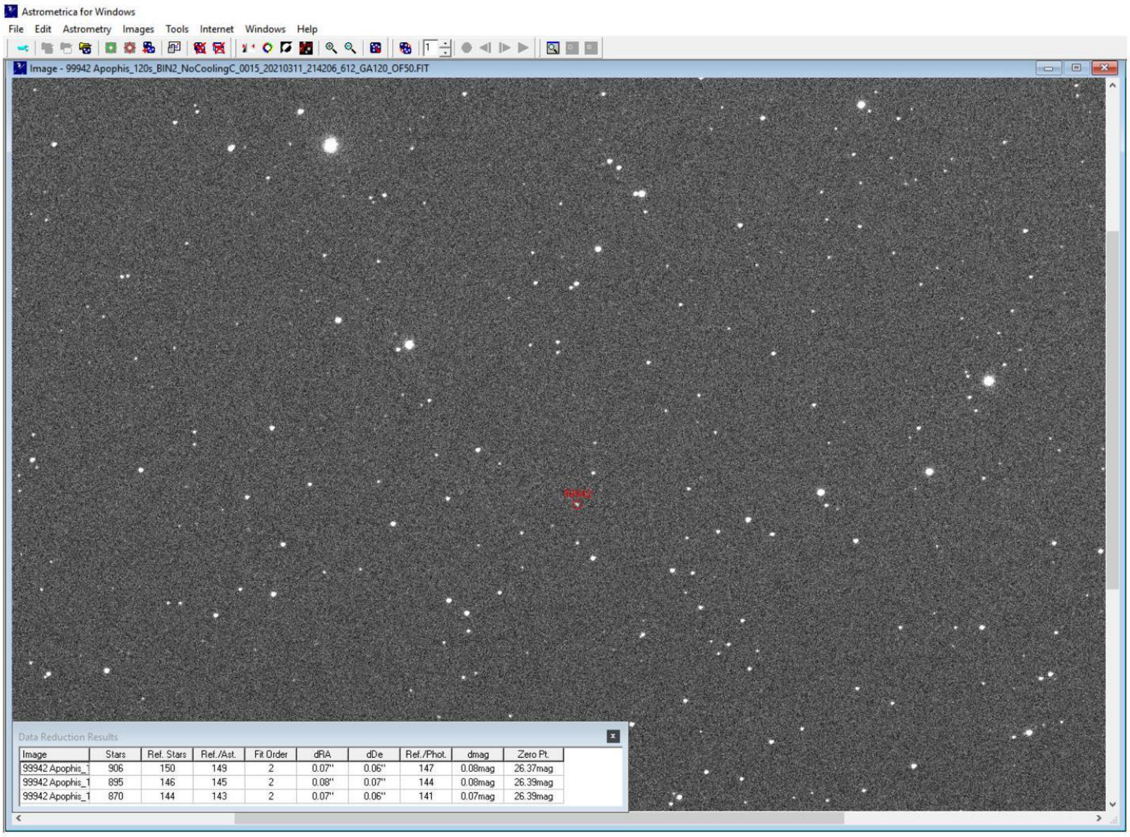

Figure 3: Image Analysis Using Astrometrica Software.

Table 3: Obtained Orbital Elements for Apophis and Ganymed

Parameter	99942 Apophis	1036 Ganymed
e	0.1913801 +/- 0.000253	0.5336047 +/- 0.00229
a	0.9225734 +/- 0.0000968	2.66694887 +/- 0.0075
i	3.33436 +/- 0.0046	26.67587 +/- 0.0006
Ω	204.04775 +/- 0.010	215.55351 +/- 0.051
ω	126.66147 +/- 0.014	132.40154 +/- 0.09
M	110.6158282 +/- 0.030	50.02086395 +/- 0.43
n	1.11225068 +/- 0.000175	0.22629868 +/- 0.000954
P	0.89	4.36
q	0.74601119 +/- 0.000312	1.24385218 +/- 0.0026
MOID	0.0001	0.3439
H	18.5	9.1

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Both asteriods' orbital elements were at Epoch 2459200.5 (2020-Dec-17.0) TDB. MPC orbital elements are available at the MPC website (MPCenter 2021). Ganymed were based on 57 observations from February 11 to March 24, 2021, with a mean residual value of 0.23". Apophis are based on 45 observations from February 14 to March 22 2021, with a mean residual value of 0.66".

The two sets of orbital elements were almost identical for both asteroids, where the maximum error was 0.2% for Ganymed and 0.1% for Apophis.

To investigate the effect of this minor difference between the orbital element sets, we used TheSkyX Professional Edition software (SoftwareBisque 2021) to obtain equatorial coordinates (J2000.0) on June 01, 2021 at 20:00 local time, as observed from M44 for each asteroid using both element sets. For Ganymed, coordinates obtained by MPC orbital elements were R.A. 07:35:06.0 and Dec. -01:03:50. For Apophis, they were R.A. 07:01:15.0 and Dec. 33:56:39. By calculating the same coordinates using the orbital elements obtained from our observations, we obtained the following coordinates: For Ganymed, R.A. 07:35:05.8 and Dec. $-01{:}03{:}52$, and for Apophis, R.A. 07:01:29.6 and Dec. 33:56:07.

The difference in coordinates was less than one arc minute. The difference for Ganymed was in order of two arcseconds only.

Table 4: 1036 Ganymed Orbital Elements Comparison between MPC and M44

Parameter	MPC	M44	%
e	0.5330949	0.5336047	0.10
a	2.6651936	2.66694887	0.07
i	26.67615	26.67587	0.00
Ω	215.5442	215.55351	0.00
ω	132.37853	132.40154	0.02
M	50.11797	50.02086395	0.19
n	0.22652228	0.22629868	0.10
P	4.35	4.36	0.23
q	1.2443926	1.24385218	0.04
MOID	0.34389	0.3439	
H	9.3	9.1	
G	0.15	0.15	

Table 5: 99942 Apophis Orbital Elements Comparison between MPC and M44

Parameter	MPC	M44	%
e	0.1915089	0.1913801	0.07
a	0.9225247	0.9225734	0.01
i	3.33677	3.33436	0.07
Ω	204.04201	204.04775	0.00
ω	126.65394	126.66147	0.01

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M	110.63213	110.6158282	0.01
n	1.1123387	1.11225068	0.01
P	0.89	0.89	0.00
q	0.745853	0.74601119	0.02
MOID	0.0002	0.0001	
H	18.91	18.5	
G	0.15		

5. Conclusion

Because orbital elements generated by the observations of our small telescope are almost identical to those obtained by numerous observations, an observer with a small telescope and correct equipment, such as camera and guiding telescope, can participate in the global campaign to observe bright minor planets. These results are valuable and can be employed by MPC to determine or refine the orbits of recently discovered asteroids or comets.

An earlier version of this paper has been presented as preprint at Research Square at this link: https://www.researchsquare.com/article/rs-1757073/v1.

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