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Measurement of Mercury Distance, by Observing Transit of Mercury

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Abstract: We will measure the distance between the Sun and the Moon by considering the Parallax and also by considering the Mercury Sun distance. The goal is to utilize the observed data. The way that we have used in this paper is based on two observational data in Iran (Mashhad 36°31′ N, 59°48′ E) and Canada (Yukon Territory 69°27′ N, 33°2′ E). It is required to mention that in Mercury transition 2016, I had personally collected the first place, Mashhad. In measuring the distance between Mercury and the Sun we have utilized the trigonometry terms and the related formulas. Using all the collected data and studying on the contacts of the mercury, has helped us to reach the best results.

Key words: Distance, Sun, Earth, Mercury, IRAN, Solar, Sun-Mercury, parallax.

Nomenclature

R_{Earth} = 150015880 =1000105867 Au
$R_{Mercury}$ = 65724412 =0.438163746 ≃ 0.43 Au
Most distance of the sun: $70 \times 10^6 = 0.46$ Au
The average distance from sun: $58 \times 10^6 = 0.38$ Au
The shortest distance to the sun: $46 \times 10^6 = 0.30$ Au
R_m = Distance between sun-mercury

r_m = Radius of the Earth

$\triangle B$ = parallax

AB =distance (|IRAN-CANADA)

α_s = Solar paralax angle of observers AB

R_e = Distance between sun- earth

1. Introduction

The start of this subject could go back to the year 1761, at which Edmond Halley had suggested a competition in the field of Mercury transition and Jin Nicolas Delicias collected some data then.

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Today the way is used for calculating the earth to Sun distance. In this paper both the Earth-Sun distance and Mercury-Sun distance have been used. The importance of this paper is due to the fact that we could use the observations to calculate the Mercury-Sun distance, using the Mercury transition. We could also confirm the previous measurements of the distance. The used formulas in this paper are all based on the results of working on this phenomenon and measuring the Sun-Earth distance. However the Mercury-Sun distance had been required.

2. Calculation for the Distance of the Sun and Earth [4]:

The point O indicated the center of the sun, C is the center of earth and M is the center of Mercury.

The observer in the point A, observes the Mercury’s position A’ on the surface of the sun. Likewise, the observer in the point B, observers the Mercury’s position B’ on the surface of the sun. Considering the theorem that: The measure of an exterior angle of a triangle is equal to the sum of the measures of the two interior angles that are not adjacent to it, for the two triangles BPM and APO:

$$\beta_B + \alpha_M = \rho_1 \;\;, \;\; \alpha_s + \beta_A = \rho_2$$

$$\rho_2 = \rho_1 \quad \rightarrow \quad \beta_B + \alpha_M = \alpha_s + \beta_A$$

The centers of Mercury, the Sun and Earth are placed on one line. Therefore:

$$\alpha_M - \alpha_s = \beta_A - \beta_B$$

where, $\Delta\beta$ is the Parallax, by simplification we will have:

$$\Delta\beta = \alpha_s\left(\left(\frac{\alpha_M}{\alpha_s}\right) - 1\right)$$

$$\tan\left(\frac{\alpha}{2}\right) = \frac{d/2}{D}$$

If α be a tiny angle therefore:

$$\tan\left(\frac{\alpha}{2}\right) = \frac{1}{2}\tan\alpha$$

By replacing them in the above equation, we have:

$$\tan\alpha = \frac{d}{D}$$

Considering the above expression and knowing that R_e and R_M are alternatively the Sun-earth distance and the Sun-Mercury distance, and that α_s and α_M are both tiny angles, we can use the below trigonometry relations in the two triangles ABO and ABM.

$$\alpha_M = \frac{AB}{R_e - R_M} \quad , \alpha_s = \frac{AB}{R_e}$$

Considering the above relations, we can calculate α_s and α_M:

$$\frac{\alpha_M}{\alpha_s} = \frac{R_e}{R_e - R_M}$$

By replacing it in the relation $\Delta\beta$, we will have:

$$\left(\Delta\beta = \alpha_s\left(\left(\frac{R_e}{R_e - R_M}\right)\right) - 1\right) = \alpha_s\left(\frac{R_M}{R_e - R_M}\right)$$

Therefore:

$$\left(\alpha_s = \Delta\beta\left(\frac{R_e}{R_M}\right) - 1\right) \qquad \text{II}$$

According to Fig. 2, α_s would be the parallax of the Sun from the views of observers A and B. The ratio $\frac{R_e}{R_M}$ can be calculated via Kepler's third law (the Mercury orbital motion (a Mercury year: 87.979 days), an earth year lasts 365.25 days.

$$\left(\frac{R_e}{R_M}\right)^3 = \left(\frac{T_e}{T_M}\right)^2 \;\; ,$$

$$\left(\frac{R_e}{R_M}\right)^3 = \left(\frac{365.25}{87.969}\right)^2 \;\; \Rightarrow \;\; \frac{R_e}{R_M} = 2.583$$

By replacing it in the expression (II), we have:

$\alpha_s = 1.583\,\Delta\beta$

Using the first relation, we can state R_e in relation (I) like this:

$$R_e = \frac{AB}{\alpha_s} = \frac{0.631\,AB}{\Delta\beta}$$

As a result, to have R_e we need the distance between the two observers (Iran-Canada) and $\Delta\beta$ of the observing data. Based on the observing data we have Table 1.

First by using trigonometry, we calculate the distance between Iran and Canada:

$$\cos(C - I) = \cos(90 - \varphi_c)\cos(90 - \varphi_I) + \sin(90 - \varphi_c)\sin(90 - \varphi_I)\cos\Delta\lambda$$

$IC = \mathrm{Cos}^{-1}\theta$

IC: (Distance of Iran to Canada)

$\cos(C - I) = \cos(90 - \varphi_c)\cos(90 - \varphi_I) + \sin(90 - \varphi_c)\sin(90 - \varphi_I)\cos\Delta\lambda$

$$\cos(21^\circ)\cos(31^\circ) + \sin(21^\circ)\sin(31^\circ)\cos(74) = 0.938(0.85) + 0.35(0.51)(0.27) = 0.79 + 0.048 + 0.838$$

$IC = \cos^{-1}(0.838) = 33.07$

$\overline{CI} = (\cos^{-1} x^\theta)$

$\overline{CI} = R_e.\theta \qquad \theta: \mathrm{Rad}$

$IC = r_e.\theta \Rightarrow IC = (6371)(33.07)\left(\frac{\pi}{2}\right) = 9481003.65 \;\; \alpha_s = \frac{9481003.65}{150000000} = 0.0632 \;\; \rightarrow \;\; \alpha_s = \frac{AB}{R_e}$

$\alpha_M = \frac{9481003.65}{150000000 - 46000000} = 0.091 \;\; \rightarrow$

$\alpha_M = \frac{AB}{R_e - R_M}$

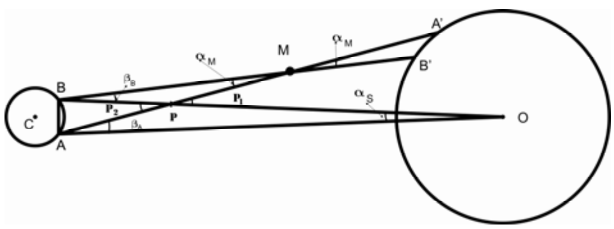

Fig. 1 Calculation for the distance of the Sun and Earth.

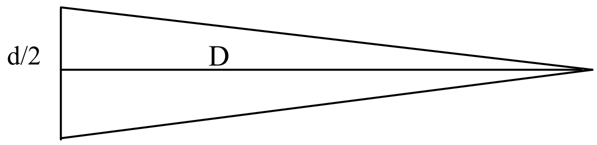

Fig. 2 Calculation for the Angle of α.

Table 1 Observation form (the transit of Mercury), Ahmad Nezam&Samaneh shamyati, Ferdowsi University ,Mashhad, Iran.

OBSERVATION FORM
The transit of Mercury

Observatory	
ObserverName:Ahmad Nezam	AssistanceName:MahsaMaram
Longitude:E 59.4881°	Latitude:N 36.3131°
Altitude:930 m	Place Name: ,Mashhad , Iran
Email address:ahmad.nezam@gmail.com	
Event Type Transit:■	
Weather	
Temperature (°C):23	Humidity (%):-
Percentage of Clear Sky (%):80	Visibility:
Tools	
Name of Telescope:TAL120	Telescope Aperture:120 mm
Focal length :1000 mm	Telescope Mounting:Equatorial
Telescope Eyepiece:00 mm	Optics:
Drive : No	Filter:baaderastrsolar film
Altitude sun Sun Alt:45°	
Event Time & Date	
Year/ Month/ Day:2016/5/9	
One contact:(h/m/s)15:41:24	
Two contact: (h/m/s) 15:44:08	
Three contact: (h/m/s) haven't been seen in Iran	
Four contact: (h/m/s) haven't been seen in Iran	
Finally time: (h/m/s) -	
Timingmethod	
Visual□	video recording□
CCD□	Photometry

Fig. 3 photo by Ahmad Nezam, Observatory of Ferdowsi University, Mashhad, Iran.

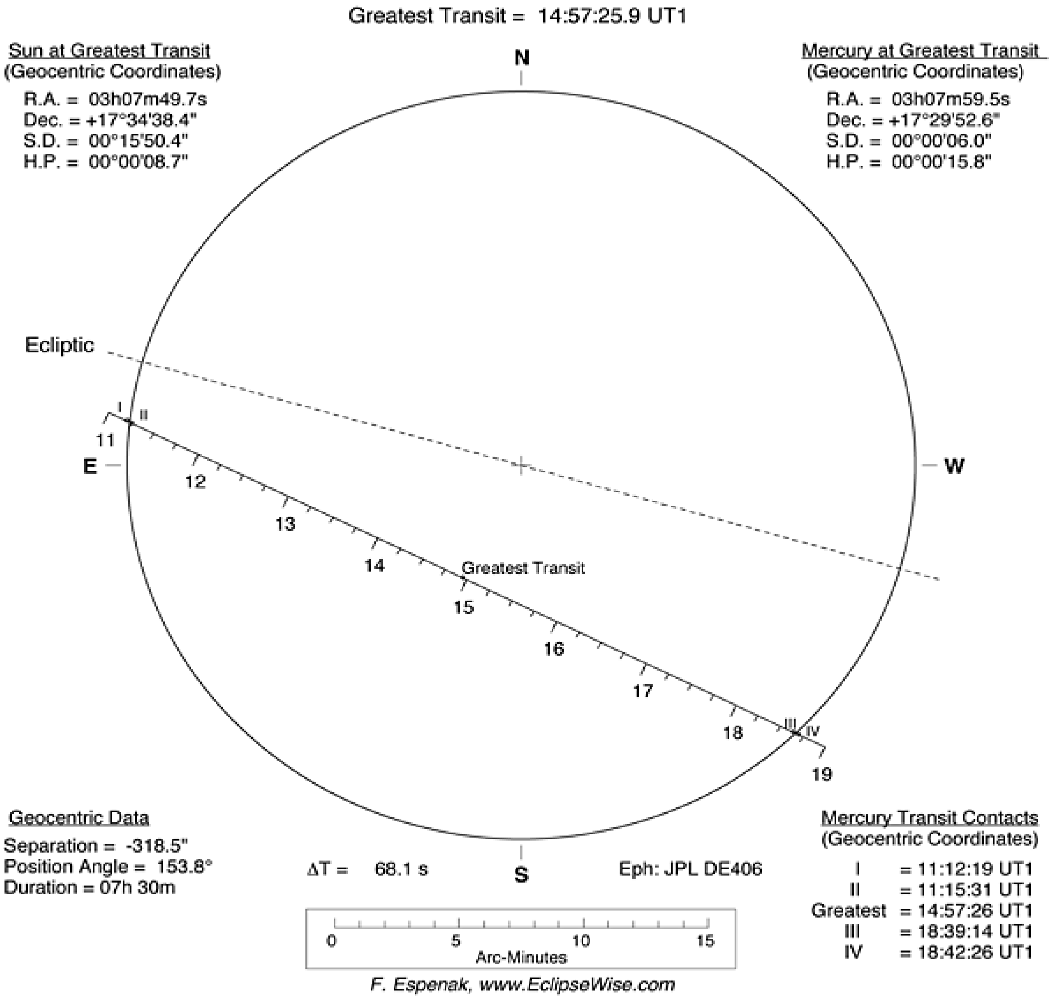

Fig. 4 Transit of Mercury :2016 May 09, F. Espenak, www.Eclipsewise.com.[1].

$$\Delta\beta = \alpha_s\left(\left(\frac{\alpha_M}{\alpha_s}\right) - 1\right) = 0.0632\left(\left(\frac{0.091}{0.0632}\right) - 1\right)$$

$$= 0.027$$

$$R_e = \frac{AB}{\alpha_s} \Rightarrow R_e = \frac{9481003.65}{0.0632} = 150015880 \text{ mK}$$

$$\begin{cases} \overset{\Delta}{BMP} : \beta_B + \alpha_M = P_1 \\ \overset{\Delta}{APO} : \alpha_S + \beta_A = P_1 \end{cases} \Rightarrow \beta_B + \alpha_M = \alpha_S + \beta_A$$

$$\Rightarrow \alpha_M - \alpha_S = \beta_A - \beta_B = \Delta\beta$$

$$\Rightarrow \Delta\beta = \alpha_M - \alpha_1 = \alpha_M\left(1 - \frac{\alpha_1}{\alpha_M}\right) \qquad \text{I}$$

$$\alpha = \frac{d}{D}$$

$$\begin{cases} \overset{\Delta}{ABO} : \alpha_1 \simeq \dfrac{AB}{R_O} \\ \overset{\Delta}{ABM} : \alpha_M \simeq \dfrac{AB}{R_O - R_M} \end{cases} \Rightarrow \frac{\alpha_1}{\alpha_M} = \frac{R_O - R_M}{R_O} = 1 - \frac{R_M}{R_S}$$

$$\overset{I}{\Rightarrow} \quad \Delta\beta = \alpha_M\left(1 - 1 + \frac{R_M}{R_O}\right) = \alpha_M \cdot \frac{R_M}{R_O} \qquad II$$

$$\left(\frac{R_M}{R_O}\right)^2 = \left(\frac{T_M}{EO}\right)^2 = \left(\frac{87.969}{365.25}\right) = (0.24)^2 \Rightarrow \frac{R_M}{R_O} = 0.24$$

$$\overset{II}{\Rightarrow} \Delta\beta = \alpha_M(0.24) \Rightarrow \alpha_M = \frac{\Delta\beta}{(0.24)} = 4.17\Delta\beta \Rightarrow \alpha_M = \frac{\Delta\beta}{R_O - R_M} = 4.17\Delta\beta \Rightarrow R_O - R_M = \frac{\Delta\beta}{4.17\Delta\beta} \Rightarrow R_M = R_O - 0.24\frac{AB}{\Delta\beta}$$

Table 2 Canada (PEI-Yukon Territory).[5].

Local Circumstances for Transit of Mercury of 2016 May 09

	External Ingress h m s	Sun Alt °	Internal Ingress h m s	Sun Alt °	Greatest Transit h m s	Sun Alt °	Internal Egress h m s	Sun Alt °	External Egress h m s	Sun Alt °
Prince Ed.Is.										
Charlottetown	08:13:24	24	08:16:36	24	11:57:35	58	15:37:57	48	15:41:08	48
Quebec										
Beauport	07:13:25	18	07:16:37	19	10:57:43	54	14:38:04	52	14:41:16	52
Brossard	07:13:27	16	07:16:39	17	10:57:47	54	14:38:08	54	14:41:19	54
Cap Chat	07:13:20	21	07:16:32	22	10:57:35	54	14:37:59	48	14:41:10	48
Charlesbourg	07:13:25	18	07:16:37	19	10:57:43	54	14:38:04	52	14:41:16	52
Chicoutimi	07:13:22	18	07:16:34	19	10:57:40	53	14:38:03	51	14:41:14	51
Drummondville	07:13:26	17	07:16:39	18	10:57:45	54	14:38:06	53	14:41:17	53
Gatineau	07:13:27	15	07:16:39	15	10:57:49	52	14:38:10	55	14:41:21	55
Hull	07:13:27	15	07:16:40	15	10:57:49	52	14:38:10	55	14:41:21	55
La Salle	07:13:27	16	07:16:39	17	10:57:47	54	14:38:08	54	14:41:19	54
Laval	07:13:27	16	07:16:39	17	10:57:47	53	14:38:08	54	14:41:19	54
Longueuil	07:13:27	16	07:16:39	17	10:57:47	54	14:38:07	54	14:41:19	54
Montreal	07:13:27	16	07:16:39	17	10:57:47	54	14:38:08	54	14:41:19	54
Quebec	07:13:25	18	07:16:37	19	10:57:43	54	14:38:04	52	14:41:16	52
Sainte Foy	07:13:25	18	07:16:37	19	10:57:43	54	14:38:04	52	14:41:16	52
Saint Hubert	07:13:27	16	07:16:39	17	10:57:47	54	14:38:07	54	14:41:19	54
St. Laurent	07:13:27	16	07:16:39	17	10:57:47	53	14:38:08	54	14:41:19	54
St.Leonard	07:13:27	16	07:16:39	17	10:57:47	53	14:38:07	54	14:41:19	54
Shawinigan	07:13:25	17	07:16:38	18	10:57:45	53	14:38:06	53	14:41:17	53
Sherbrooke	07:13:27	17	07:16:39	18	10:57:46	54	14:38:06	53	14:41:17	53
Tr. Riviares	07:13:26	17	07:16:38	18	10:57:45	53	14:38:06	53	14:41:17	53
Verdun	07:13:27	16	07:16:39	17	10:57:47	54	14:38:08	54	14:41:19	54
Saskatchewan										
Moose Jaw	--	-	--	-	08:57:59	32	12:38:33	57	12:41:44	57
Regina	--	-	05:16:24	-1	08:57:58	33	12:38:32	57	12:41:43	57
Saskatoon	--	-	05:16:20	-1	08:57:56	31	12:38:31	55	12:41:43	55
Yukon Territory										
Dawson	--	-	--	-	07:57:30	14	11:38:33	37	11:41:45	37
Whitehorse	--	-	--	-	07:57:38	15	11:38:37	40	11:41:48	41

"2016 Transit of Mercury", Fred Espenak, *Observer's Handbook 2016*, Royal Astronomical Society of Canada

Table 3 Geocentric phases of the 2016 transit of Mercury. [2, 3].

Event	Universal Time	Position Angle
Contact I	11:12:19	83.2°
Contact II	11:15:31	83.5°
Greatest Transit	14:57:26	153.8°
Contact III	18:39:14	224.1°
Contact IV	18:42:26	224.4°

3. Results and Discussion

Now we should replace the numbers in the equations. Therefore, we would have the distance between the Sun and Earth. Then according to Fig. 1 and calculation via Spherical trigonometry, we can measure the distance between the Sun and Mercury.

$$\begin{aligned} R_M &= 150000000 - 0.24\frac{9481003.65}{0.027} \\ &= 150000000 - 84275588 \\ &= 65724412 = 0.4 \text{ Au} \end{aligned}$$

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