GEOS GEOS CIRCULAR ON ECLIPSING BINARIES GEOS
EB 30 2011 January 29
23 Parc de Levesville
F – 28300 BAILLEAU l'Evêque

VISUAL ESTIMATES and TAROT MEASUREMENTS of MP Del

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ABSTRACT : MP Del is an EA binary star. The eclipses are rare and last long overlapping a whole night. It is hardly possible to observe them more than 3 times in the year and therefore visual observations were not conclusive. Tarot measurements allow a confirmation and an improvement of the results given by Otero and Dubovsky (2004). We obtain : Min I : 2 454 242.40 + 21.3384 E with Min II ocurring at phase 0.553. The eccentricity of the orbit is $0.083 \leq e \leq 0.101$. The direction of our solar system is inclined by 1.8° to the orbital plane of the two components of the system.

RESUME : MP Del est une variable à éclipses longues et rares. Les éclipses durent plus longtemps que la nuit et il n'est guère possible d'en observer plus de 3 par saison, c'est pourquoi les observations visuelles n'ont pas donné de bons résultats. Les mesures effectuées par les télescopes Tarot ont permis de confirmer et d'améliorer les résultats déjà publiés par Otero et Dobovsky (2004). On obtient les éléments : Min I : 2 454 242.40 + 21.3384 E ; le Min II tombe à la phase 0.553. L'excentricité du système vérifie : $0.083 \leq e \leq 0.101$. La direction de notre système solaire est inclinée de 1.8° par rapport au plan de révolution des deux composantes de MP Del.

RESUMEN: MP Del es una variable con eclipses largos y raros. Los eclipses duran más que la noche y es imposible observar más de 3 por temporada, es por eso que las observaciones visuales no dieron buenos resultados. Las medidas efectuadas por los telescopios Tarot permitieron confirmar y mejorar los resultados ya publicados en el IBVS 5557. Obtenemos los elementos: Min I: 2 454 242.40 + 21.3384 E; el Min II ocurre a la fase 0.553. La excentricidad del sistema verifica: $0.083 \leq e \leq 0.101$. La dirección de nuestro sistema solar está inclinada 1.8 ° con relación al plano de revolución de los ambos componentes de MP Del.

RIASSUNTO : La binaria MP Del mostra un periodo di 21.3384 d ed una durata delle eclissi comparabile con la durata delle notti. Di conseguenza, l'osservazione visuale, limitata a soli tre minimi per anno, non ha permesso di ottenere risultati conclusivi. E' solo grazie alle misure dei telescopi robotici TAROT che si e' potuta migliorare l'effemeride giungendo a Min I=2 4545 242.40 + 21.3384 x E, con il minimo secondario che cade a fase 0.553. Si e' potuto confinare l'eccentricita'orbitale nell'intervallo 0.083-0.101 e ricavare un'inclinazione del piano orbitale di 1.8 gradi rispetto alla linea vista.

1. INTRODUCTION

MP Del has been observed by GEOS members since 1998. It is an eclipsing binary, usually at magnitude 7.4 but the star appears sometimes fainter. However in August 2004, on the night 21-22th, a minimum was undoubtedly observed.. Analysing other possible minima, DMT thought the period to be 5.669 days though Otero and Dobovsky (2004) gave the elements :

$$\text{Min I}: 2\,448\,246.30 + 21.3387\,E \qquad (1)$$

This ephemeris forecast indeed a minimum for August 22.056.

2. The 2005-2006 OBSERVATIONS

375 estimates were carried out by GEOS members. Table 1 gives the name of the observers, their acronyms, number of estimates, epoch of observations, mean magnitude at maximum, standard deviation (at maximum) and number of possible observed minima.

F. GOBET 2006	GBF	97	13/08 – 14/11 2006	6.88	0.11	1
DUMONT 2005	DMT	76	2/06 – 20/11 2005	7.44	0.06	2
DUMONT 2006	DMT	56	6/06 – 15/12 2006	7.48	0.05	1
CHECCUCCI 2005	CHC	37	15/06 – 17/10 2005	7.42	0.07	1
PAMPALONI 2005	PMP	36	6/06 – 10/09 2005	7.35	0.10	6
F. GOBET 2005	GBF	36	19/09 – 11/12 2005	7.24	0.20	0
M. BISSON 2005	BIM	27	11/06 – 7/09 2005	7.38	0.07	4
JACQUET 2005	JTP	10	31/05 – 29/08 2005	6.95	0	2

Table 1

The mean magnitude at maximum is different for GBF and JTP because of the large magnitude difference between the comparison stars A and B (1.45 magnitudes). When searching for possible minima, we obviously retained the difference between the mean magnitude at maximum and the observed magnitude of the same observer. The analysis of the observations did not allow to conclude, therefore we consulted the Tycho and Hipparcos measurements and the ASAS results, communicated to us by Anton Paschke. ASAS obtained 6 faint points : 4 points at JD 2 452 376.10 which is phase 0.50 of the ephemeris :

2 448 246.3 + 21.342 E (2)

used by Anton Paschke and 2 points at phase 0.95 of the same ephemeris. If we transfer the primary minimum to phase 0 , the secondary one occurs at phase 0.55 , thus deriving ephemeris (3) :

Min I : 2 452 364.36 + 21.342 E
Min II : 2 452 376.10 + 21.342 E (3)

Unfortunately, ephemerides (1) and (3) are not in agreement :
- With ephemeris (1) , Min I of (3) falls at phase 0.9855, i.e. more than 7 hours too early. One may think that (3) would improve the period but it does not because the period derived from (3) is longer.
- With ephemeris (3), the primary minimum given by (1) falls at phase 0.0443, that is 22 hours too late. However, we must note that the times given by Hipparcos are doubtful : at the time of Min I, the brightness of the star decreases until the last measurement and it is not possible to know if the minimum was actually reached. Moreover, according to Tycho, Min I should have occurred earlier. At minimum II, the situation is reversed : the brightness increases immediately from the first measurement but according to Tycho, this minimum should have occurred later.

The periodograms are not conclusive.
However, from our 375 observations, ephemeris (1) and (3) and the results of Tycho and Hipparcos, we obtain ephemeris (4) :

Min I : 2 448 246.31629 + 21.33908 E
Min II occurs at phase 0.5427 (4)

But this ephemeris (4) leaves some unexplained differences and therefore we had to use TAROT measurements.

3. TAROT MEASUREMENTS

There are two TAROT telescopes : one in Calern, the other in Chile. These two instruments are 250 mm automatic telescopes designed for instantaneous observations of Gamma Ray Bursts. Both telescopes observed MP Del from May 2007 (JD 2 454 223) to November (JD 2 454 410) ; some further observations were carried out later.

The first result is that the eclipses are long, lasting more than 11 hours, and that explains the observed differences in the previous observations.

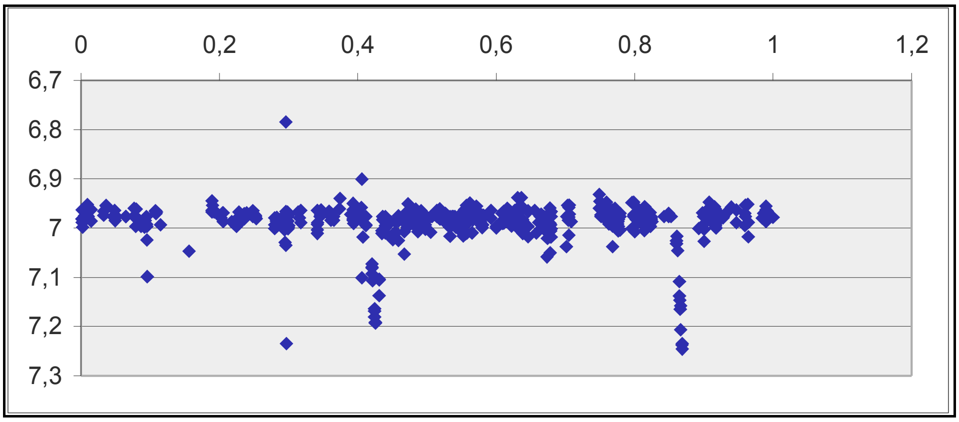

Figure 1 : The phased B light curve obtained by TAROT Chile with period P = 21.3384 days ; phase 0 was arbitrarily chosen.

The TAROT telescopes provide 4 series of measurements (Calern, Chile, B and V) and have partly observed 8 different minima.

Table 2 : Results of the TAROT measurements

Site / Filtre	Number of measur.	Magn. at max.	Standard deviation	Number of mini	Min I mag.	Min I JD (UT)	Min II mag.	Min II JD (UT)
Chili B	616	6.986	0.0396	3	7.25	54242.354	7.19	54232.880
Chili V	614	7.362	0.0538	4	7.65	54242.474	7.55	54232.858
Calern B	715	6.974	0.0688	6	7.32	54242.409	7.19	54232.849
Calern V	711	7.307	0.0678	5	7.62	54242.366	7.51	54232.849

The eclipses are long : the primary minimum lasts 0.63 day (± 0.05 d.) i.e. more than 15 hours. The secondary minimum lasts 0.47 day (± 0.03 d.), i.e. more than 11 hours. The colour variation is smaller than the possible errors of measurements. The (B – V) colour index is :

	CHILE	CALERN
Max	- 0.376	- 0.333
Min I	- 0.40	- 0.30
Min II	- 0.36	- 0.32

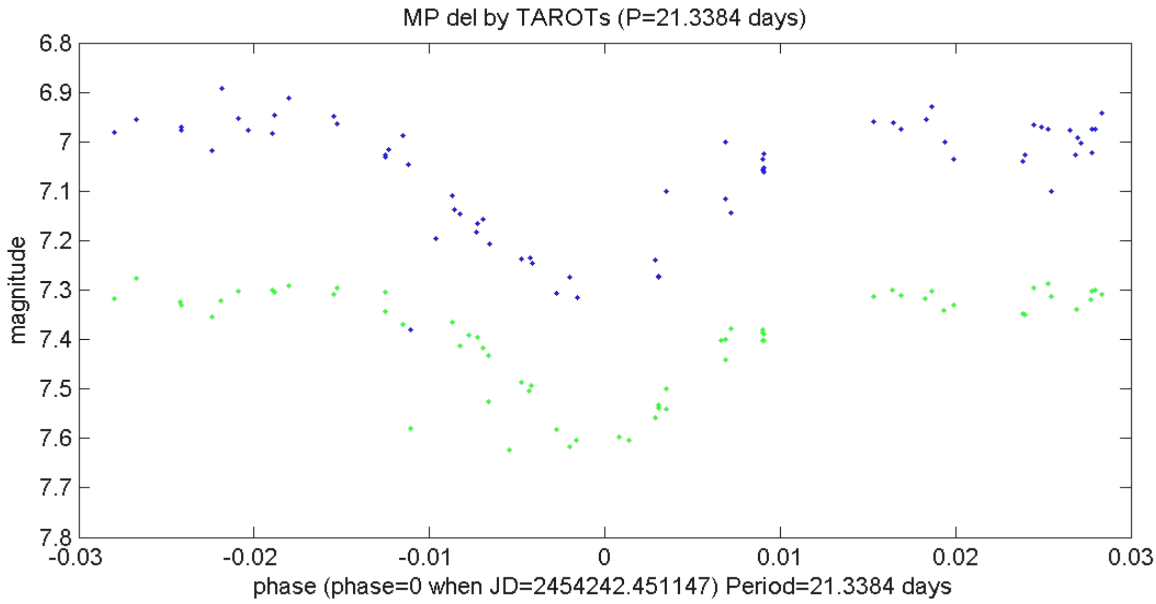

Fig. 2 : Min I of MP Del by the TAROT telescopes in B (blue dots) and V (green dots).

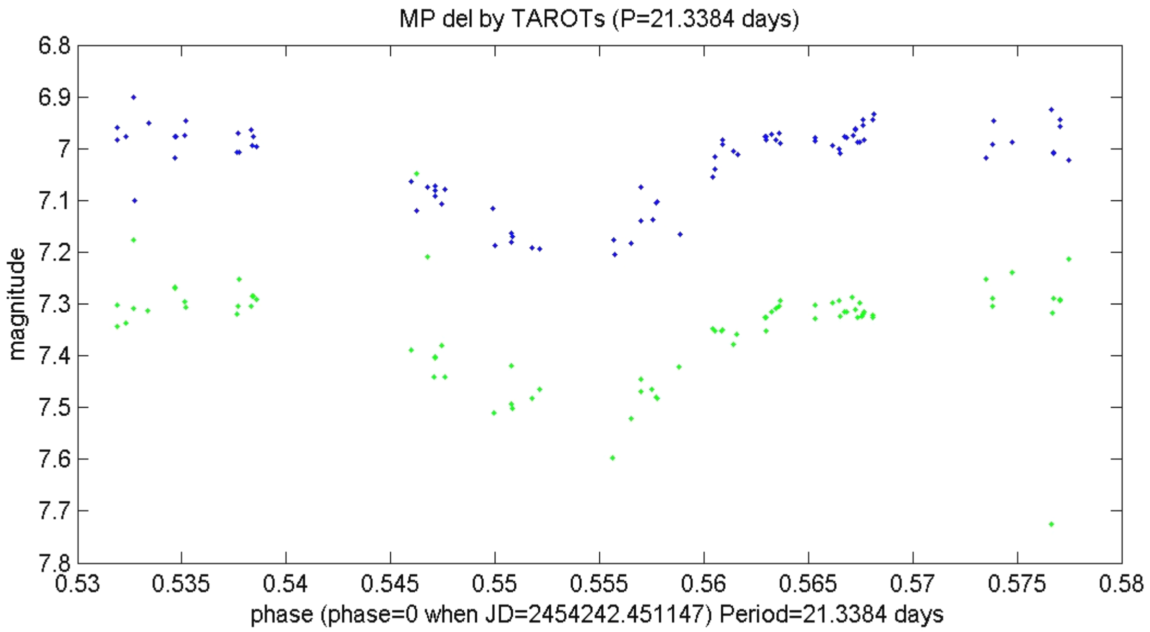

Fig. 3 : Min II of MP Del by the TAROT telescopes in B (blue dots) and V (green dots).

4. PERIOD and EPHEMERIS

To compute the period, we used the four times of Min I given in table 2 and the time from which ephemeris (1) is derived as given by Otero and Dubovsky (2004) and computed after the Hipparcos measurements. Ephemeris (5) is then obtained:

Min I : JJ 2 454 242.40 + 21.3384 E (5)
± 0.03 0.0005

Min II falls at phase 0.553. The revised period we adopt is 21.3384 days = 21 d 8 h 7.3 min. The eclipses happen roughly at the same times every 64 days, which means that many years would be required to improve the results.

5. MP Del PHYSICAL PARAMETERS

The catalogues attribute an A3 V spectrum to MP Del. The Tarot measurements give V = 7.33 at maximum,
Depth of Min I in V : 0.30 mag
Depth of Min II in V : 0.20 mag.
No significant colour change during the eclipses.
The period is **21.3384** days or **0.0584214** year.

5.1 Physical parameters

As the colour does not change during the eclipses, we think that the two components are similar, but not identical, because Min I is deeper than Min II. We suppose that the primary component is an **A 3 V** star and the companion an **A 5 V** star. From the standard models we can derive **Table 3** :

	Component 1	Component 2
Spectrum	A 3 V	A 5 V
Absolute magnitude	1.7	2.1
Mass (Sun = 1)	1.97	1.79
Radius (Sun = 1)	1.66	1.55
Luminosity (Sun = 1)	15.85	10.96

5. 2 Semimajor axis of the relative orbit of star 2 around star 1.

If we express the distances in A.U. (astronomical units) and the period in years, applying the third Kepler's law gives :

$a^3 / T^2 = M_1 + M_2 = 3.76$ T = 0.05842 year a = 0.234 AU

5.3 Distance of MP Del.

The absolute global magnitude of MP Del (from spectral type and luminosity class) is 1.13 and its apparent global magnitude is 7.33, which gives a distance of 174 parsecs (567 l.y.), assuming no stellar extinction.

6. CONDITIONS OF THE ECLIPSES

The depth of the eclipses proves that they are not total, so the first step is to compute the ratio of the apparent area of the star occulted by its companion.

6.1 At primary minimum

Star 1 is partly occulted by star 2. Figure 4 shows the position of both stars during the primary minimum. Let S_1 , S_2 and S_3 be the area of the three defined domains.

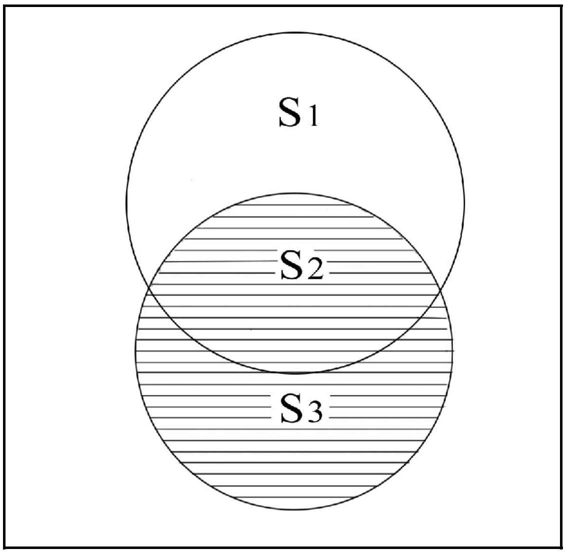

Fig. 4

The ratio $\mathbf{S_2 / (S_1 + S_2)}$ can be determined thus :

We have :
$$7.63 = -2.5 \log \left(L_2 + L_1 \frac{S_1}{S_1 + S_2} \right) + k$$

$$7.33 = -2.5 \log (L_2 + L_1) + k$$

where L_1 and L_2 are the luminosities of the stars. We obtain :

$$\mathbf{S_2 \ / \ S_1 + S_2 = 0.408}$$

i.e. 40.8 % of star 1 is hidden by star 2.

6.2 At secondary minimum :

A similar calculation shows that 41.1% of star 2 is hidden by star 1.

6. 3 Apparent distance of the centres of the stars at the minima.

Figure 5 shows the situation at the primary minimum.

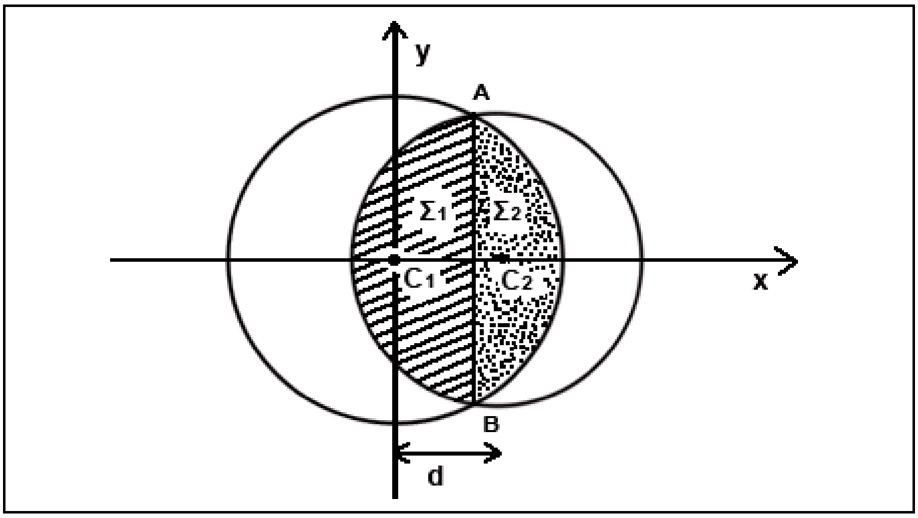

Fig. 5

Let C_1 be the centre of star 1, C_2 the centre of star 2 . The origin of coordinates is in C_1, and d is the apparent distance between C_1 and C_2 expressed in Sun radius. The two stellar disks intersect in A and B, whose abscissa α is given by :

$$\alpha = (0.3531 + d^2) \ / \ 2d$$

We compute the areas Σ_1 (hatched on fig. 5) and Σ_2 (dotted).

$$S_2 = \Sigma_1 + \Sigma_2$$

satisfying the condition :

$$S_2 \ / \ (S_1 + S_2) = 0.408$$

for the occulted area of the disk of star 1 .

$$S_1 + S_2 = \pi \, . \, (1.66)^2$$ is the area of the disk of star 1.

$$\Sigma_2 = \frac{5.51}{2} \left(\arccos\left(\frac{\alpha}{1.66}\right) - \frac{\alpha}{1.66}\sqrt{1-\left(\frac{\alpha}{1.66}\right)^2} \right)$$

$$\Sigma_1 = \frac{4.805}{2} \left(- \arccos\left(\frac{\alpha - d}{1.55}\right) + \frac{\alpha - d}{1.55}\sqrt{1-\frac{(\alpha - d)^2}{1.55^2}} + \pi \right)$$

$$\Sigma_1 + \Sigma_2 = S_2 = 0.408 \, (\Sigma_1 + \Sigma_2) = 0.408 \ \pi \, 1.66^2 = 3.532$$

A Maple computation yields Table 4, keeping in mind that condition **$S_2 / (S_1 + S_2) = 0.408$ (or $S_2 = \Sigma_1 + \Sigma_2 = 3.532$)** has to be satisfied.

Table 4

d	Σ_1	Σ_2	S_2 / ($S_1 + S_2$)	$S_2 = \Sigma_1 + \Sigma_2$
1	2.778	2.146	0.569	4.924
1.3	2.210	1.820	0.465	4.030
1.4	2.036	1.703	0.432	3.736
1.45	1.952	1.644	0.415	3.596
1.47	1.919	1.620	0.4088	3.539
1.472	1.9155	1.618	0.4082	3.5335
1.473	1.914	1.617	0.4078	3.5310
1.48	1.902	1.608	0.4055	3.510
2	1.12	0.994	0.244	2.114

Finally, **1.472 < d < 1.473**(primary minimum) and by a similar computation
1.625 < d' < 1.630 (secondary minimum)

We note that $d \neq d'$ and that the eccentricity of the orbit is not negligible as shown by the position of Min II , i.e. not half way between two consecutive Min I.

7. INCLINATION OF THE SYSTEM

The fact that the eclipses are partial implies that the Earth is not exactly in the orbital plane of the two components. The results obtained above allow us to compute the inclination i of the direction of the Earth. (figure 6)

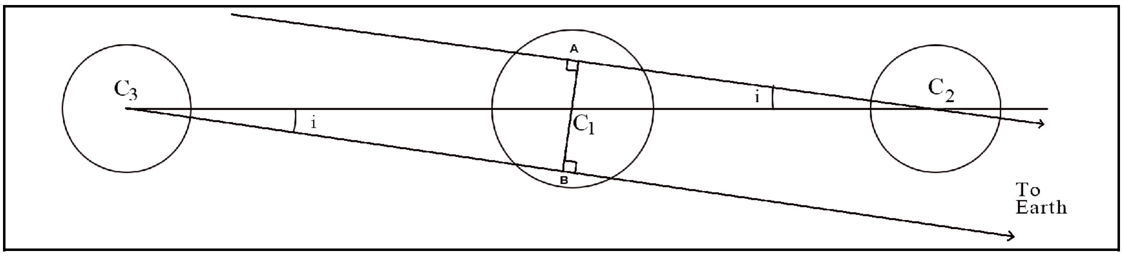

Fig. 6

$AC_1 = d = 1.472$ $C_1B = d' = 1.626$

$C_1C_2 \neq C_1C_3$ but as the difference is small, we can suppose as a first approximation that $C_1C_2 = C_1C_3 = 0.234$ AU, which yields a value for sin i :

$$1.6° < i < 1.9°$$

This result will be refined further down.

8. PARAMETERS OF THE ELLIPSE

8.1 The origin O is set at the geometrical centre of the elliptic orbit of star 2 around star 1 .

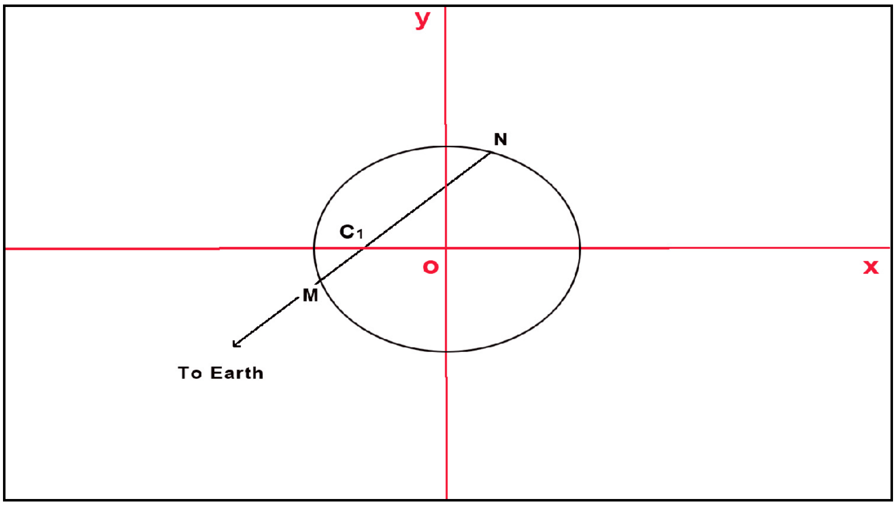

Fig. 7

Min I happens when star 2 is in M and Min II happens when star 2 is in N. Let us determine the eccentricity of the ellipse and, if possible, the angle (OC_1N) formed by the major axis and the direction of our solar system. We can obtain an approximation of $\mathbf{C_1N / C_1 M}$ on figure 6 :

$$\sin i = AC_1 / C_1C_2 = 1.47 / C_1C_2 \quad \text{and} \quad \sin i = 1.63 / C_1C_3$$

Then, $\quad C_1C_3 / C_1C_2 = 1.63 / 1.47 = 1.109$

Hence, on figure 7, $\quad C_1N / C_1 M = 1.109$

The ellipse being given, we can fix a lower limit for the eccentricity since the hatched area limited by (MN) (figure 8) will be minimal when (MN) is perpendicular to the major axis of the ellipse. Applying second Kepler's law, this hatched area represents 447/1000 of the whole area of the ellipse, it follows that the hatched area on figure 8 has to be smaller than 447 / 1000 of the area of the whole ellipse. Hence (hatched area) < (447 / 1000) π . ab where a is the semi major axis, b the semi minor axis and $c = OC_1$

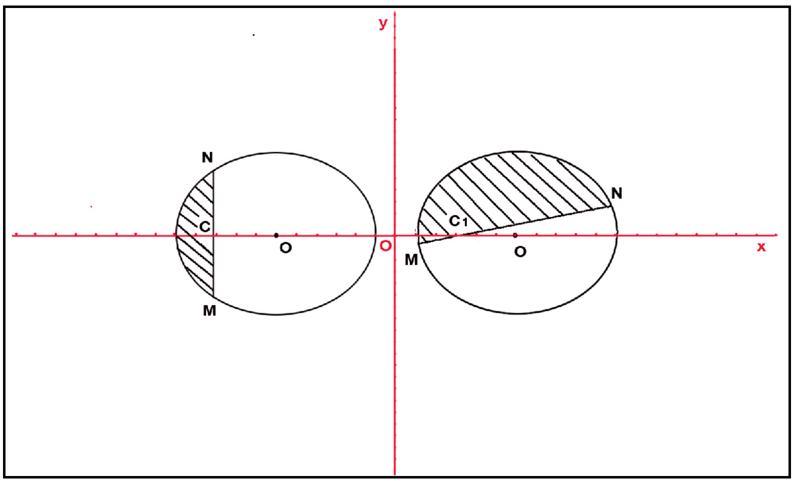

Fig. 8

$$\int_{-a}^{-c} b\sqrt{1-\frac{x^2}{a^2}}\,dx \quad < \quad \frac{1}{2}\ 0.447\ \pi\, ab$$

This leads to the inequation : π - arccos (- e) - e$\sqrt{1-e^2}$ - 1.4043 < 0

where $e = \frac{c}{a}$ is the eccentricity of the ellipse.

whose solution is e > 0.08334

8.2 Figure 9 shows the ellipse of centre O and focus C_1 where star 1 is situated. Star 2 has a retrograde motion on this ellipse whose periastron is A. The circle of centre O and radius OA = a is tangent to the two vertices of the ellipse.

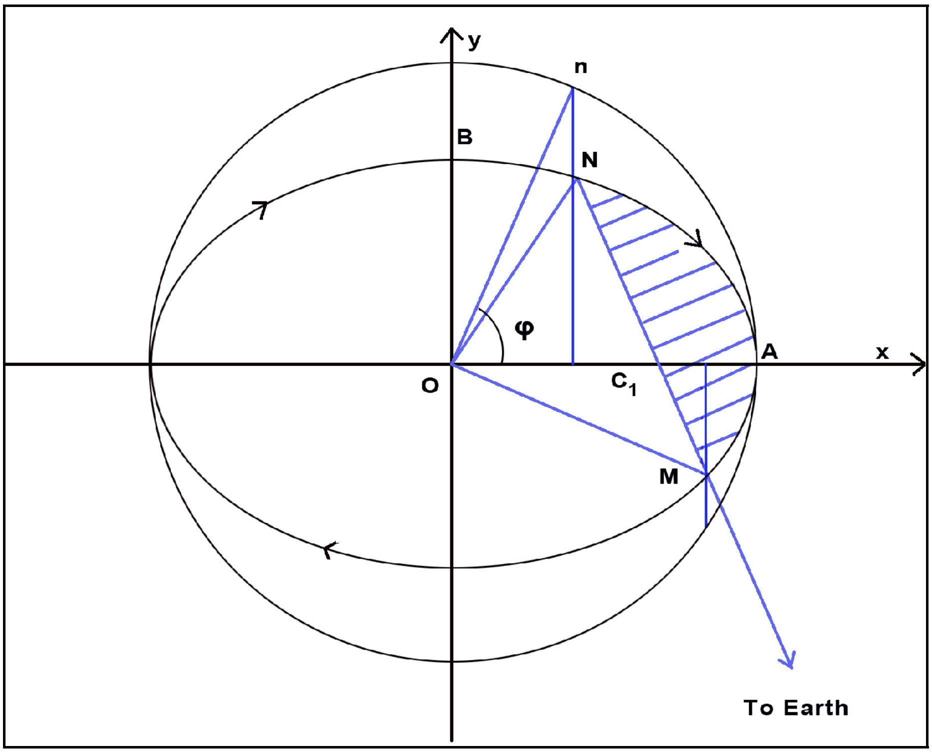

Fig. 9

To obtain the area of an elliptic sector, it is easier to compute the area of a circular sector and then transform the result by an affinity whose ratio is b / a = OB / OA. Let the hatched area (NAM) of the ellipse be 0.447 of the whole area. We then obtain the equation :

$$\frac{1}{2}\ ab\ \left(\arccos\left(\frac{x_N}{a}\right) + \arccos\left(\frac{x_M}{a}\right)\right) - \frac{1}{2}\ c\ (\ y_N + |y_M|\ ) - 0.447\ \pi\, ab = 0$$

where (x_N , y_N) and (x_M , y_M) are the respective coordinates of N and M. We can express y_N , y_M and x_M as functions of x_N and b , thus arriving at an equation $f(b, x_N) = 0$ where f is a function of the two variables b and x_N . The two properties $C_1N / C_1M = 1.109$ and the position of the secondary minimum were indeed used in this calculation. The equation $f(b, x_N) = 0$ has several solutions which form the intersection of $\mathcal{G}$, the graph of f and plane $z = 0$. (figure 10)

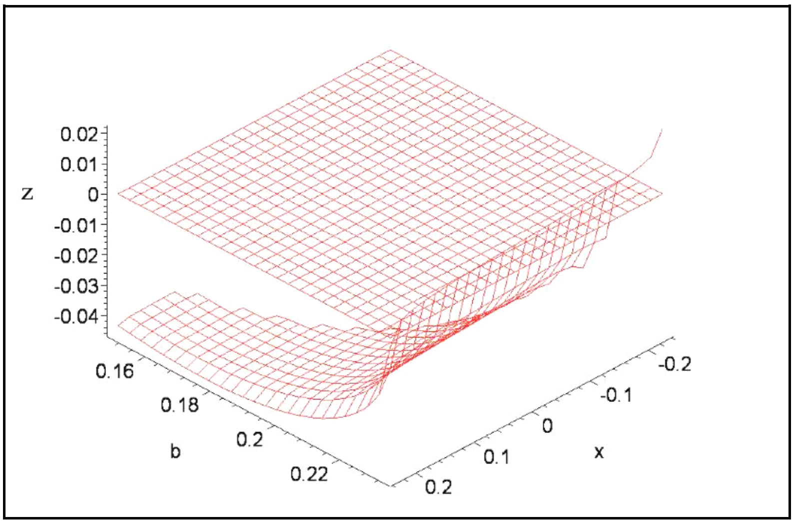

Figure 10 : The graph $\mathcal{G}$ and plane $z = 0$ drawn by a Maple computation.

The numerical calculation yields Table 5 :

a	**b**	**c**	**e**	**x_N**
0.234	0.234	0	0	
	0.2334	0.0167	0.0716	0.1165
	0.2333	0.0181	0.0773	0.0739
	0.2332	0.0193	0.0826	0.0262
	0.2331	0.0205	0.0876	-0.0198
	0.2330	0.0216	0.0923	-0.0607
	0.2329	0.0227	0.0968	-0.0970
	0.2328	0.0237	0.1011	-0.1322
	0.2327	No solution		

Table 5

The results are :

$$0.0833 \le e \le 0.1011$$
$$0.2328 \le b \le 0.2331$$
$$0.0205 \le c \le 0.0237$$
$$-0.133 \le x_N \le -0.020$$

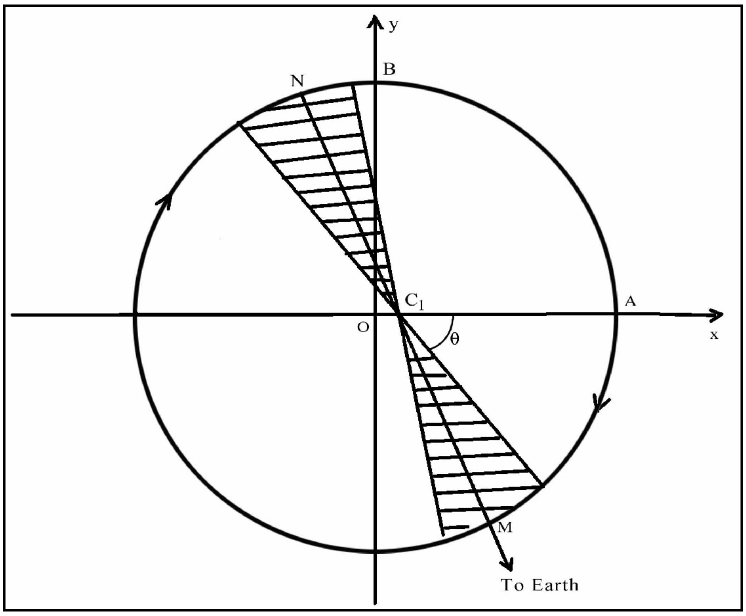

Figure 11 : The probable model of the orbit of star 2 around star 1.
51° < **θ** = angle (OC_1N) = angle (AC_1M) < **80°**

In fine, this calculation used the two properties and we can refine the inclination (§ 7, fig. 6). If c = 0.0237 (maximum value) :

$$\textbf{Sin i} = BC_1 / C_1C_3 = (1.626 \times 695700) / (0.247 \times 149\,598\,000) = 0.0306$$

Hence i = 1.75 °. If we choose the minimum value : c = 0.0205, we obtain i = 1.84 ° or in round figures :

i = 1.8°.

Références :

Otero, Sebastian A ; Dubovsky, Paval A , 2004, IBVS 5557 : New elements for 80 eclipsing binaries IV.
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Anton PASCHKE : Personal communication.