GRAVITY ANOMALY DURING THE MOHE TOTAL SOLAR ECLIPSE AND NEW CONSTRAINT ON GRAVITATIONAL SHIELDING PARAMETER

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Abstract. By using a high-precision LaCoste-Romberg gravimeter, continuous and precise measurements were carried out during the March 9, 1997 total solar eclipse in Mohe region in Northeast China. The gravity variations were digitally recorded during the total solar eclipse so as to investigate the possible anomaly of the Sun and the Moon's gravitational fields on the Earth. After the careful processing and analysis of the observed data, no significant anomaly during the very solar eclipse was found. However, there are two 'gravity anomaly valleys' with near symmetrical decrease of about $6 \sim 7$ μgal at the first contact and the last contact. This is the anomaly phenomenon observed and reported for the first time in the literature. This paper is intended to explain the observed anomaly by conducting the tilt experiment due to the thermal stress and temperature change in the solar eclipse. A new constraint limit on gravitational shielding is thus obtained. Some analysis and discussions are presented although further studies and research are highly needed.

Keywords: Solar eclipse, gravitation, Majorana shielding, totality

1. Introduction

The study of the properties of gravitation is an important theoretical topic. One of the long-standing difficult problems in this area is the possibility of 'gravitational shielding','absorption', or 'bending'. Since Bottlinger proposed the hypothesis of gravitational absorption in 1912 and later Majorana's gravitational shielding (Majorana, 1920) in 1920, there have been many attempts to measure the gravitational variations during solar eclipses in the past several decades so as to detect the possible effect of the Moon's shielding on the Sun's gravitational field (Wang et al., 2000; Eckhardt, 1990; Capato, 1961; Slichter et al.) on the Earth. In particular, a very precise measurement of vertical gravity variations has been carried out during the Mohe total solar eclipse in 1997, and the puzzles remain unexplained.

It is well-known that the gravity on the Earth's surface consists of gravitational attractions and centrifugal force. In addition to the Earth's gravitational field, the other celestial bodies also have gravitational attractions among which those by the Sun and Moon contribute about 99% of the total. Therefore, the search for

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the gravity variations at a given position on the Earth's surface shall begin from the studies of the gravitational variations by the Sun and Moon. As the relative position of the Earth with respect to the Sun and Moon is changing, so does the gravitational field, and thus the gravitational tide changes on the Earth. This tide varies with time and space, and it also depends on the interior state and the physical properties as well as motion of the Earth in addition to the relative position with respect to the Sun and Moon. However, for a given point, the variation is mainly due to the component of the periodical gravitational tide. The difference of the theoretically calculated gravitational tide and the observed results is the variations after deduction of the theoretical tide, and this can be the starting point of the analysis of the residual variations and find out the possible contribution factors.

The observation of gravity variations during a solar eclipse is the method of considering the possible effect of the Sun's gravitational field in the shadow region of a solar eclipse in a similar way as that of light being shielded or absorbed, or the possibility of bending by the moon's gravitational fields so that it might have some effect in the shadow region on the Earth? However, there might be some effect in gravity or maybe the effect is null. Thus, the method is to measure the vertical gravitational variations during the period of a solar eclipse including a certain period before and after the eclipse. Theoretically speaking, there exist unanswered questions about the correlation of gravity decrease, increase or even zero variations and the possibility of gravitational absorption, superimposition or cancellation of the possible gravitational shielding. However, in reality, it would be very important materials whatever the experimental results are. By using the high-precision gravimeter (LaCoste-Romberg D) with a precision of μgal together with the continuous digital recording system, the observation was conducted in Mohe during the solar eclipse (Wang et al., 2000), which provides important real data for the studies of possible 'gravitation shielding, absorption or bending'.

2. Observations and Results

The observations during the total solar eclipse in March 9, 1997 were carried out at the Mohe observation center of the Institute of Geophysics, Chinese Academy of Sciences, its location is: $\phi = 53°29'20''$N and $\lambda = 122°20'30''$E, which lies in the center of the shadow of the totality during the eclipse. The local times of the total eclipse are: first contact at $08^h03^m29^m$, second contact at $09^h08^m18^s$, third contact at $09^h11^m04^s$, and last contact at $10^h19^m50^s$. The duration of the totality of the solar eclipse is 2 mins and 46 seconds. The angular height of the Sun during the totality is 21°.

The outer environment of the observation station: the gravimeter during observations was placed in quiet, dry room without any interference at a room temperature of 15°C. The power supply was stable and the gravimeter was kept at a constant temperature. A very high-accurate LaCoste-Romberg D gravimeter (D-

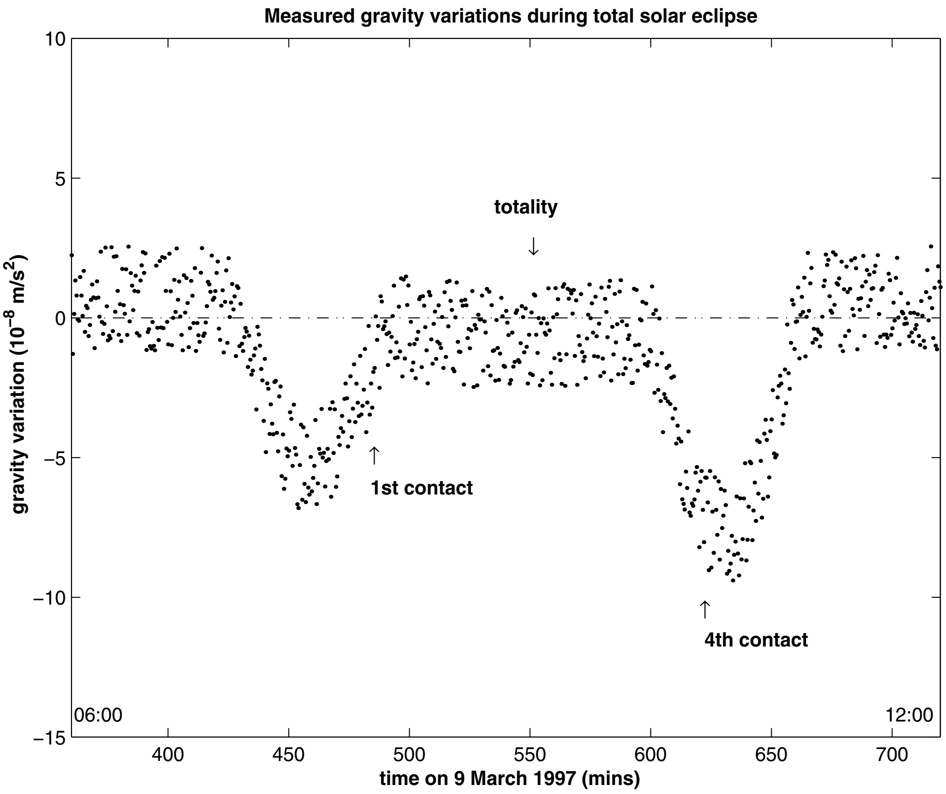

Figure 1. Measured gravity variations during the Mohe solar eclipse.

122) was used to measure the variations of vertical gravitational acceleration with a high precision of $2 \sim 3 \times 10^{-8}$ m/s^2 or $2 \sim 3$ μgal . The equipment was kept in a constant temperature with ± 0.1°C inside an undisturbed room. The output signal of the gravity variations from the gravimeter was automatically collected by a PC with an A/D card and recorded as digital signals for further processing.

The measurements were from 6:00 am on 8 March to 23:00 pm on 10 March 1997 for the eclipse recording with a sampling rate of one recording per minute. According to the timing of the solar eclipse, the measurement procedure and sampling rates are: $06^h00^m \sim 07^h00^m$ and $11^h00^m \sim 24^h00^m$ at the rate of 1 recording per minute with a total 840 gravity data; $07^h00^m \sim 09^h00^m$ and $09^20^m \sim 11^h00^m$ at the rate of 2 recordings per minute with a total of 440 data; and $09^h00^m \sim 09^h20^m$ at a higher rate of 1 recording per second with a total of 1200 data.

The results of gravity observations: The gravity variations with a total of 2580 measurements recorded from 06:00 am to 23:00 pm on 9 March 1997 are shown in Figure 1.

3. Anomalies and Analysis

3.1. THE EFFECTS OF TEMPERATURE AND PRESSURE

According to the calibration precision of the LaCoste-Romberg (L & R) gravimeter provided by the manufacturer, the variation of 8°C in temperature would lead to 5 μgal change in gravity reading. This variation is even small under the condition of constant temperature. The actual temperature change in controlled room temperature (15°C) during the eclipse is within ± 1°C, so the actual effect of temperature change is less than 1 μgal . Therefore, it is not necessary to make the correction due to temperature variations.

The actual change in pressure during eclipse from 07:00 am to 11:00 am on 9 March 1997 is about 1 mmH and the change is less than 3 mmH in that whole day. According to the manufacturer, the effect of actual pressure change on gravity reading in 9 March 1997 shall much less than ($\ll 1$ μgal), and thus no correction is necessary.

The measured variations of vertical gravity including the gravitational tides which can be calculated theoretically. The difference between theory and measured variations is the residual anomaly during the solar eclipse. The residual gravity varies within $\pm 3 \sim 4$ μgal around zero, but there exists two unknown anomalies (with the amplitude of $6 \sim 7$ μgal) in the about 20min around 07:28 am, and in the 20min around 10:19 am, respectively. These timings are coincident with the first and last contacts. We referred to these anomalies as the '*gravity anomaly valleys*', and this is the first time in literature recorded during a total solar eclipse.

3.2. THE ANOMALY FROM THE SECOND CONTACT TO THE THIRD CONTACT

By analysing the measured data during the Mohe solar eclipse on 9 March 1997, there is no gravity anomaly > 3 μgal from the second contact ($09^h 08^m 18^s$) to third contact ($09^h 11^m 04^s$. This the third phenomenon apart from the 'two valleys'. These insignificant variations around the totality are very difficulty to explain and there may be many possible explanations. We give three possibilities:

1. There is no absorption, unlike light forming the shadow by the Moon, of the Sun's gravitation attraction on the Earth, so that there is no anomaly observed around the totality (Ducarme et al., 1999).
2. The possible anomaly is too small, the present gravimeter is not precise enough to capture such signals or the signal is the same level as noise.
3. There might be some gravitational absorption by the Moon in the shadow region, but there exists some superimposition of gravitational attractions near shadow region as the Sun, Moon and Earth are on the same line. The absorption is cancelled by the superposition, so that the result is a very low level small signal, which was not observed during this solar eclipse.

These three explanations or assumptions are all related to the basic concept of gravitation. However, the insignificant variations of gravity during this eclipse do not necessarily imply that there is no change of gravitation as the phenomena sometimes seemingly contracts with its essence. Thus, it is extremely necessary to do further observations and investigations.

3.3. The Anomalies Before and After the Solar Eclipse

As for the two gravity anomalies observed just before and after of the solar eclipse in Mohe, we will not use the complicated mathematical, astronomical or celestial methods. We shall mainly focus on the basic concept of gravity, the equipment used and the environment as well as other possible influence factors:

For the influence of pressure, the first anomaly occurred during the increase of pressure from 07:15 am to 07:40 am, this corresponds to the decrease and then increase of the gravity in a shape of funnel valley where pressure increased sharply and then slowly, then stayed steady to slowly decrease ($07^h40^m - -10^h12^m$). In the slowly decreasing stage from 10^h12^m to 10^h45^m, the gravity variations again decreased then increased forming another anomaly valley. These comparison show that there was no synchronisation or any correlation of pressure with gravity variations. If there were any effect of pressure changes (the effect of atmospheric load), the gravity change should be in the same pace (even with a delay synchronisation) with the pressure, and these two anomalies should not occur in the period when there is no significant changes in pressure.

Considering the effect of temperature change, it was suggested in the literature (Ducarme et al., 1999) that the quick decrease in temperature in the shadow region during a solar eclipse can directly or indirectly affect the gravity variations. In the occurrence of the two anomalies in the Mohe solar eclipse, the internal temperature of the equipment and the room temperature where the equipment was kept were all constant, and there was no sign of influence by the outer temperature changes. In addition, the outside temperature changes were in the periods of 07^h15^m to 07^h40^m and 10^h12^m to 10^h45^m. These slight increase in temperature all occurred not in the period of the solar eclipse, and there were no sudden increase or decrease in temperature. Even the change in temperature during the totality of the solar eclipse is not enough to produce the two gravity anomalies about one hour before or one hour after the totality. Therefore, the temperature change in the shadow region cannot be the responsible factor.

The gravitational tide is a change on a global scale. Even the totality was only about 2 minutes and 46 seconds when the shadow was centered at the observation station. When the two anomalies occurred, the shadow region was hundreds of kilometers far away from the observation point, and this was not possible to affect the point of observation in term of any possible shadow effects. Considering the possible effect of ocean tides, the Mohe station is about one thousand kilometers away from the sea, the local tide of ocean type is not relevant.

What is the possible implication in astronomy and gravitation? What is the relation with the basic concept of gravitation? There are a series of open questions.

The authors will focus mainly on the gravity and its principle in the rest of the discussions.

Firstly, the two anomalies in gravitation variations have an amplitude of about $6 \sim 7$ μgal , which is $2 - 3$ times of the standard error of the gravimeter. The two anomalies all last about 30 to 40 minutes with several thousands of recordings (forming the shape of these anomalies), which imply that the anomalies were not due to some observation errors or random signals.

Secondly, according to the principles of gravitation, some possible reasons or cases responsible for the $6 \sim 7$ μgal anomalies are:

- From the point of view of the Earth's movement, the increase of ground level could lead to small decrease in the gravity variation at the observation point, while the subsidence could give rise to a small increase in gravity. According to the theoretical formula [6], the increase of 3cm in ground level may reduce the gravity by $6 \sim 7$ μgal .
- The possible redistribution of underground mass due to motion could induce some gravity changes. The mass (or density) decrease shall reduce the gravity at a certain point, and vica versa.
- The superimposition forcing may be enhanced in the direction of the Moon and the Sun, so as to reduce the gravity at the Earth's surface.
- Other unknown reasons.

For the first two cases2, these require that the ground suddenly moves up about 2–3 cm, then sudden moves down with certain symmetry, and this should happen twice; or these require the underground mass (e.g., groundwater) flow out of the region and flow back again, and repeat twice. These are impossible from the point of view of geosciences. In addition, in the near two hours before or after solar eclipse, the shadow of totality was near hundreds or even thousands of kilometers away from the observation station, and it was very unlike to cause any repeatable gravity variations.

For the reason in the third case – the superimposition of the gravitational attractions by the Moon and the Sun might be enhanced. From the measured data, one can see that the superimposition could be enhanced or weaken in the first anomaly valley, and this repeat again in the second anomaly valley. This could be related to the essential properties of gravitation.

3.4. Effect of Ground Tilting and Thermal Stress

As the puzzles presented in out preliminary results (Wang et al., 1999) remain unexplained, there are various explanations and suggestions we received from our the scientists all over the world. One interesting explanation is given by Weiss [9] at MIT. He suggested that von Kluber (1960) reviewed the various solar eclipse where the tilting of the earth during the eclipse could possibly cause some errors. Then, Weiss (private communications) proposed that the observed effect in the total solar eclipse could be due to thermally induced tilt and the tilts must have been reasonably large – as large as 0.1 milliradian – since the effect to be unipolar must be second order. The projection of g along the gravimeter axis changes away from parallel for both positive and negative tilts. The thermal gradients are maximum at the beginning and end of the eclipse and go to zero during the eclipse.

In order to investigate the effect of ground tilt due to thermal stress and temperature change, first we use the recorded the temperature variations during the solar eclipse, the maximum temperature change out the lab room (the temperature only variations with $\pm 1°$C inside the room), thus its effect on the gravity variations is $< 1\mu$gal . However, as the ground tilt was not measured during the solar eclipse. We have recently conducted a ground tilt in the similar environment where we used the liquid nitrogen to could down the outside ground in the nearly same pace and duration as the real solar eclipse to simulate the temperature variations so as to measure the ground tilting movement. We found that the ground tilting is much less 0.01 milliradian for a temperature change of 2 degree. In order to achieve the 0.1 milliradian with an equivalent effect of 5 μgal , the necessary temperature change must be ± 20 degree. This was definitely the case in the real solar eclipse. In addition, even this could be the contribution factor to the puzzle, we still could not explain sure the double peaks could repeat and locate in the first and last contacts.

Even *inside* the room, we force the a two peak temperature change of 10 degree so as to simulate the two anomalies, after removing the high frequency variations, we still found a residual relatively smooth curve (solid curve in Figure 2) whose variations still remain unexplained. Thus, the observed puzzles could be due to the ground tilt and thermal stress, however, it is very unlike to cause the anomalies with such high values as observed during the total solar eclipse. Therefore, more observations with much more careful design shall be done in the future in order to resolve this effect and the observed puzzles.

Another explanation is given by Andrews (1997) whose suggested that the gravitational field has a velocity-dependent and circular propagation component (Andrews, 1997). This is interesting and promising, and thus suggests that more observation is absolutely necessary.

3.5. NEW CONSTRAINT OF GRAVITATIONAL SHIELDING PARAMETER

Besides all possible explanations of the observed data, Unnikrishnan et al (2001) argued that the observed variations does not necessarily support the hypothesis of gravitational shielding. By using our data, they calculated a very accurate constraint on the Majorana parameter h

$$h \leq 2 \times 10^{-17}\mathrm{cm}^2/\mathrm{g}, \tag{1}$$

which was the best limit. By using the same method and the observed data after the ground tilt corrections, we can estimate a new constraint on Majorana parameter

$$h \leq 6 \times 10^{-18}\mathrm{cm}^2/\mathrm{g}, \tag{2}$$

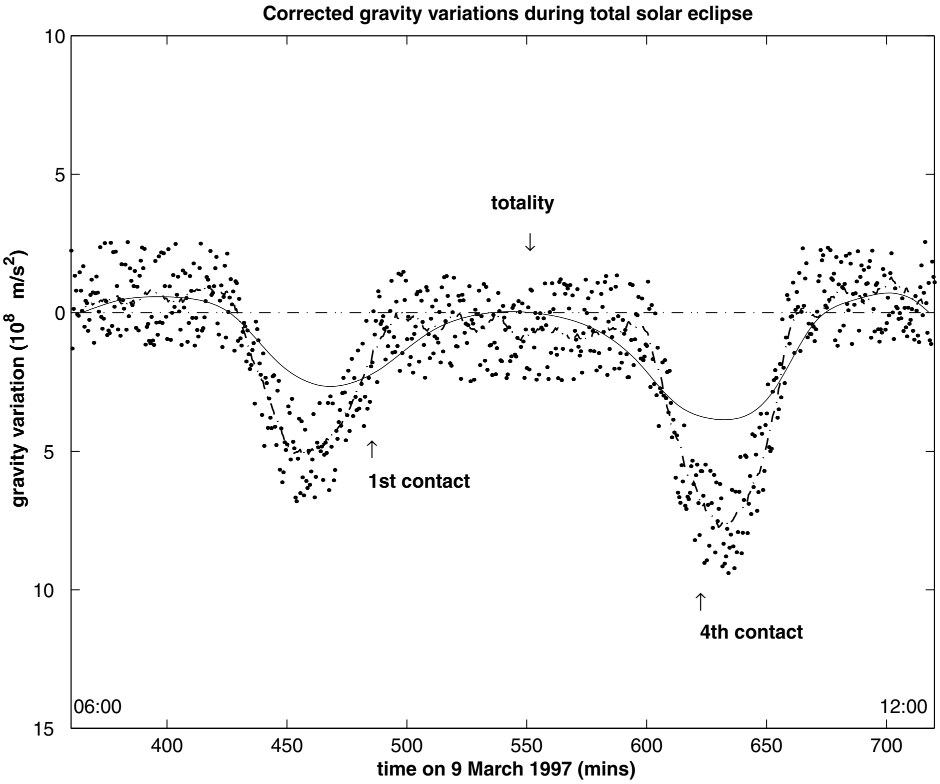

Figure 2. Gravity variations after the simulated ground tilting corrections.

which is the best limit obtained so far. Thus, whatever the explanation for the puzzles, we can at least provide a new constraint on the strength of the possible gravitational shielding.

4. Conclusions

The observations during the Mohe solar eclipse show no significant gravity variations during the solar eclipse from the first contact to the last contact. Therefore, the possible gravitational absorption or shielding remains undetermined. More high-precision gravimeters and longer time recordings shall be used during the future solar eclipses.

There were, however, two unexplained gravity anomaly valleys observed from the Mohe solar eclipse on 9 March 1997. There has not been such kind of anomalies reported in the literature. This may be related to the fundamental properties of gravitation and may have very important scientific implications. This shall attract more basic research with a combination of researchers from astronomy, celestial mechanics and other disciplines.

The re-confirmation of such unexplained gravity anomalies are also very important although the chances of total solar eclipses are relatively rare, and the observational measurements are difficult. However, more observations and gravity measurements with many gravimeters are yet to be carried out in the future eclipses in the shadow region of the totality. At the same times, the measurements of pressure, temperature and water level as well as ground level shall be conducted simultaneously, so as to provide more detailed and mutual comparable data for further analysis.

The authors would like to present these unexplained gravity anomalies to the worldwide researchers for further studies. We would be especially interested in making more observations and collaborations for the coming solar eclipse on 4 December 2002.

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