Search for the Gravitational Absorption Effect Using Spring and Super-conducting Gravimeters during the Total Solar Eclipse of August 11, 1999

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Abstract

In this paper we analyse the gravimetric records obtained with tidal instruments, during the solar eclipse on August 11, 1999, when the shadow crossed Europe.

Measurements recorded with spring and super-conducting gravimeters set up in Annelles, Uccle, Walferdange and Bondy are discussed.

Comparisons between super-conducting gravimeters and spring gravimeters are made, in order to fix the limits of the magnitude of abnormal effects in relation to the possibility of a shielding effect by the Moon on the Sun's gravitational attraction. The results from the LCR and Askania gravimeters will also be discussed in the paper.

Our conclusions are that significant effects during an eclipse, if indeed they do exist, may be below the noise level of the gravimeters which is ±1nm/s² (0.1µGal) for super-conducting gravimeters.

Our findings confirm that in these situations both spring and super-conducting gravimeters are working at the limits of their precision, with a risk that abnormal environmental features induced by the eclipse could significantly modify the signals.

Keyword: *gravity, gravitational shield, gravimeter, solar eclipse, Earth-tide*

1. Introduction

An interest for gravity measurements during an eclipse by Tomaschek (1955) arose from the experiments and hypothesis of Majorana (1920) on gravitational absorption, often referred to as the *Majorana effect,* or, *gravitational shielding*. The validity of Majorana's hypothesis has been questioned by Russell (1921). Tomaschek's experiment was followed by gravimeter experiments during solar eclipses in the early sixties by Slichter, Caputo and Hager (1965) and many others. A comprehensive review of gravimetric and barometric observations during eclipses has been given by Sun (1995).

The failure to observe any significant change in *g* during eclipses in the early nineteen-sixties resulted in a hiatus of similar experiments for a period of about 30 years.

Recently Ducarme, Sun, d'Oreye, van Ruymbeke and Mena Jara (1999) reported on gravimeter and microbarometer observations during the 1991 eclipse in Mexico.

This was followed by a collaborative campaign for the November 3rd, 1994 Eclipse (De Freitas et al. 1995).

On March 9th, 1997, in China, there occurred a total eclipse of sun. During the eclipse, in Moho, Heilongjiang province, China, which was in the shadow centre of the eclipse, Wang *et al.* (2000) carried out a series of gravity measurements. Their purpose was to detect the possible effect of gravitational shielding during a total eclipse. The observation instrument they used was a LaCoste-Romberg D gravimeter (L&RD-122). After all necessary corrections, the residue shows two significant gravity decreases. One occurred during the first contact with amplitude of 5.3±1.4µgal. Another occurred during the last contact with amplitude of 6.8±1.4µgal. Wang et al suggest that these two gravity changes may result from some extraordinary phenomenon associated with gravity, such as the possible shielding effect by the moon on the gravitational force of the sun. However, they also stated that more high precision measurements should be carried out in the future, to further study this phenomenon, especially during solar eclipse.

The main goal of this paper is to compare, for the eclipse of August, 11th, 1999, measurements recorded by spring gravimeters and by super-conducting gravimeters in order to determine the reality of the effects recorded in China.

2. Spring and super-conducting gravimeters monitoring

For events with few hours duration, spring gravimeters can resolve significant changes in *g* of 10^{-8}ms^{-2} (1µGal). The super-conducting gravimeters (SGs) can resolve changes of 10^{-9} ms^{-2} (0.1µGal). So SGs are more suitable for observing the possibility of effects like shielding, which may be extremely small, if indeed they exist. However, because the SGs are not as easily transportable as spring gravimeters, almost all eclipse experiments are conducted with transportable spring gravimeters.

3. The August 11th, 1999 Eclipse monitoring with super-conducting gravimeters

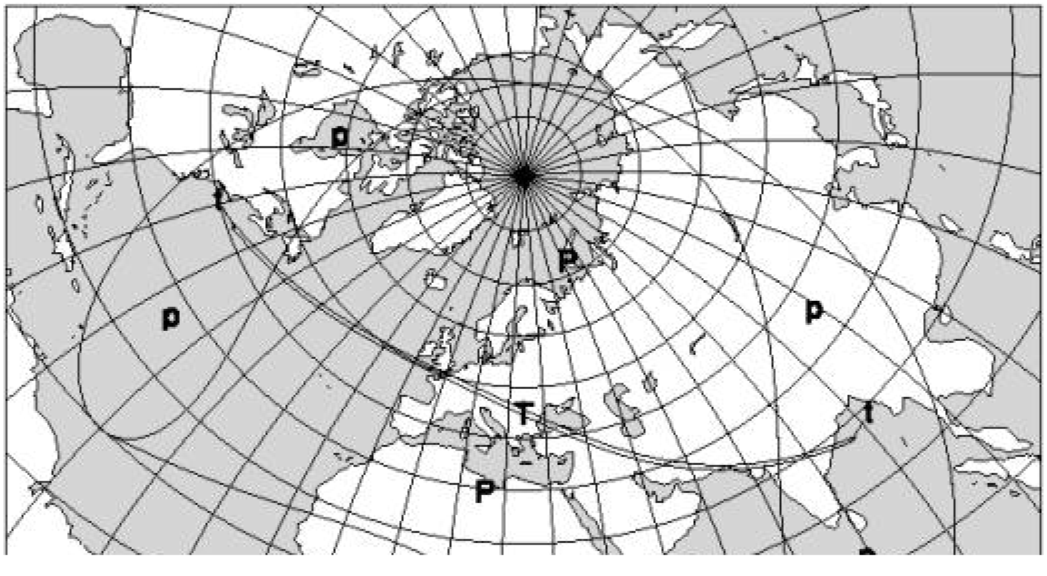
The results of a collaborative observation campaign of gravimetric monitoring observed during the eclipse on August 11, 1999 over Europe (fig.1) are given below.

On August 11, 1999 a total eclipse occurred in Europe. The shadow path passed near to four SG stations at Uccles and Membach, (Belgium), Strasbourg, (France) and Vienna, (Austria). It provided a unique opportunity to search for the gravitational shielding effect with the more sensitive SGs.

Lalu *et al.* (2001) described the gravity measurement, processed the data and discussed the results. After tides and air pressure corrections, the results of the four SG stations show that the super-conducting gravimeter has the same limitation of noise as the transportable spring gravimeters for this type of experiment and there is no perceptible change in *g* above the ambient noise level during the totality. The records from the Vienna SG will be discussed in order to fix the limit of precision in detecting existing phenomena with this high quality probe.

The SG GWR C025 in the Vienna station, which is located at the NW margin of Vienna, has been recording gravity and air pressure continuously since 1995.

This station lies very close to the main path of the eclipse in Europe on August 11, 1999. Its sun obscuration was 99% during that eclipse. The first and last contacts for the eclipse at the Vienna station were 9:23.5 and 12:08.6 respectively, totality was at 10:46.2.



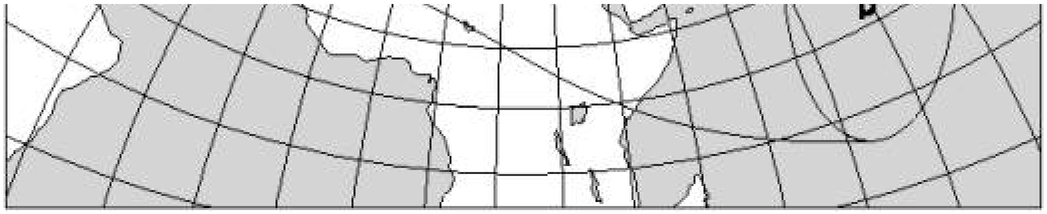


Figure 1: Shadow zones for August 11, 1999 Solar Eclipse. The Totality zone (T) crosses Europe; The P zones are penumbra areas.

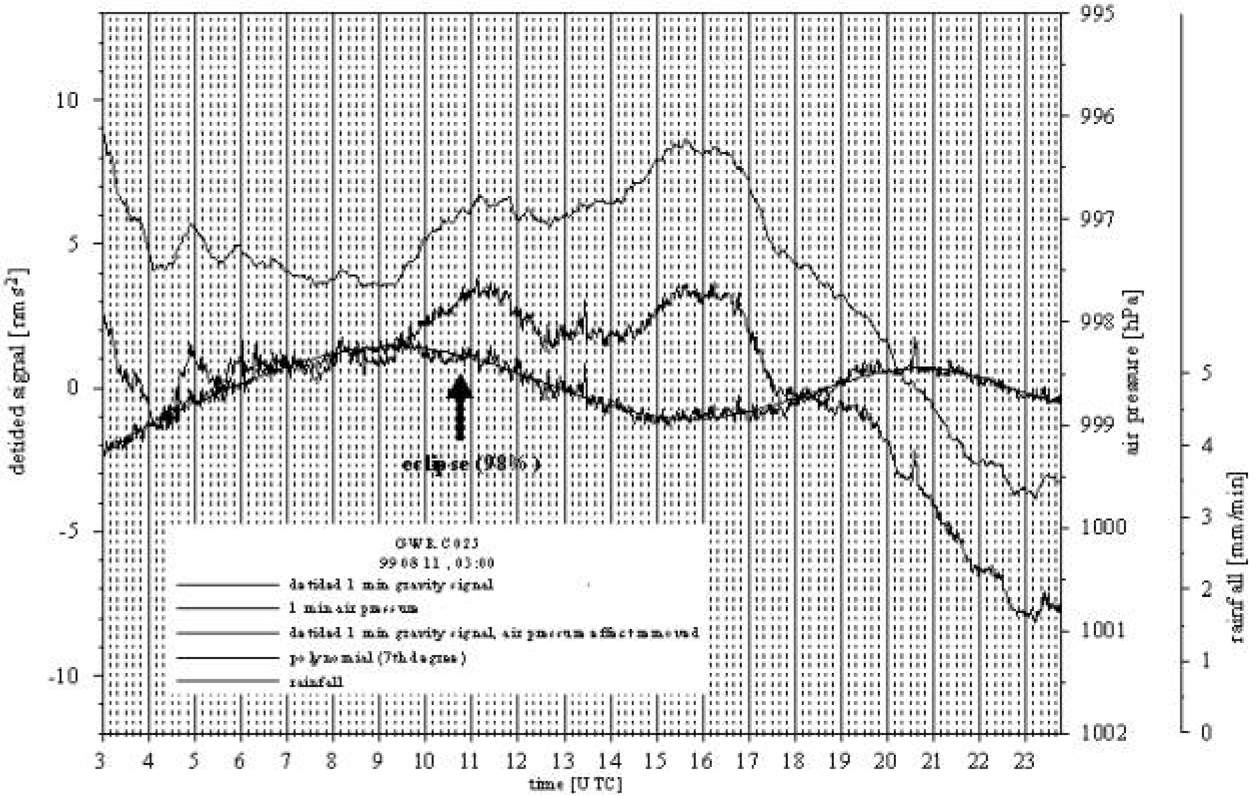


Fig. 2: Gravity and air pressure during the eclipse on August 11, 1999, in Vienna observed with SG C025. The upper curve shows the pressure changes, the middle curve shows the gravity residues and the lower curve shows the gravity residues corrected for pressure. The first and last contacts for the eclipse at Vienna station are 9:23.5 and 12:8.6 respectively, totality was at 10:46.2.

Meurers processed the gravity and air pressure data of the Vienna station during that eclipse. The results he obtained are showed in Fig.2. All curves have been filtered, so the sample interval is 1 min. The upper curve shows the air pressure changes. The middle curve shows gravity changes after tidal correction. There is a good correlation between these two curves. After the air pressure effect was subtracted from the gravity effect, by applying a constant admittance factor of $-3.53 \mathrm{nms}^{-2}/\mathrm{hPa}$, the gravity residual became smooth, which is shown by the lower curve. The gravity changes remaining in the residual signal, obtained after application of the corrections of tides and atmospheric pressure effects, is lower than 0.4 μGal for periodicities comparable to semi-diurnal process. For the periodicity of the eclipse modulation, oscillation amplitudes are less than 0.1 μgal.

4. The August 11th, 1999 Eclipse integrated monitoring with spring and super-conducting gravimeters

In order to monitor the possible shielding effect of the Sun's attraction during a Solar eclipse, the Royal Observatory of Belgium set up a network of gravimeters with LCR, Askania and SG for the eclipse of August

11th, 1999. It was centred on the village of Annelles in northern France, within the zone of totality. Gravity changes were observed in parallel with the air pressure, temperature, luminosity and rainfall (van Ruymbeke,M. & al.,2001). Among the stations within the network were Annelles, Uccle ,Walferdang and Bondy stations.

The results from each of these stations are discussed below.

4.1 The result from Annelles station

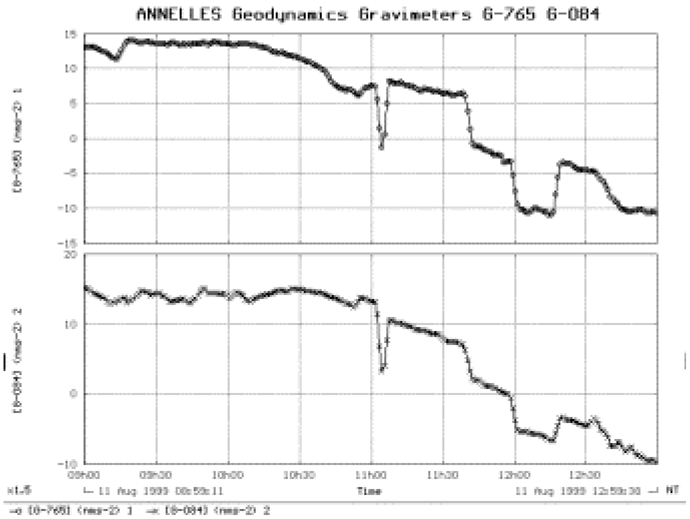


Fig.3: Gravity changes from 3:00 to 12:30 on August 11, 1999 at Annelles station. The two curves show the de-tided records of gravity changes for the gravimeters Geodynamics G-765 (top) and G-084 (bottom). The first and last contacts at Annelles station are about 9:00 and 12:00 respectively, with totality at 10:30

Two Geodynamic gravimeters were used to carry out the gravity measurement during the 11 August 1999 eclipse at the Annelles station. Fig.3 shows the gravity changes during the eclipse from 9:00 to 13:00. The first and last contacts at Annelles station are about 9:00 and 12:00 respectively, totality was at 10:30.The gravity curves are obtained after tides and air pressure correction. All the data was filtered by 10 min. There is a very good correlation between these two curves, with the overall tendency, shown by the two curves, being a decrease. No abnormal gravity that was beyond 0.2uGal for SG and 1 uGal for LCR were detected. So no shielding effect beyond noise level was found to exist.

4.2 The result from the Uccle station

At the Uccle station a Super Conducting Gravimeter and a LCR gravimeter were use to conduct the gravity measurement. Fig.4 shows the gravity change from 9:00 to13:00, 11 August 1999. *The first and last contacts at Uccle station are about 9:00 and 12:00 respectively, with totality at10:30.* The gravity changes are air-pressure-corrected and tides-corrected. All data was filtered by 2 min. In Fig.4, the first curve shows the gravity change recorded by the SG and the second one shows the gravity change recorded by the LCR gravimeter. The overall tendency of the first curve is a decrease. The overall tendency of the second curve is a rise. There is no obvious correlation between the two curves. No common abnormal gravity change that is beyond 1μGal for the SG and the LCR gravimeter is detected. So again no visible shielding effects beyond noise level were found to exist during the eclipse.

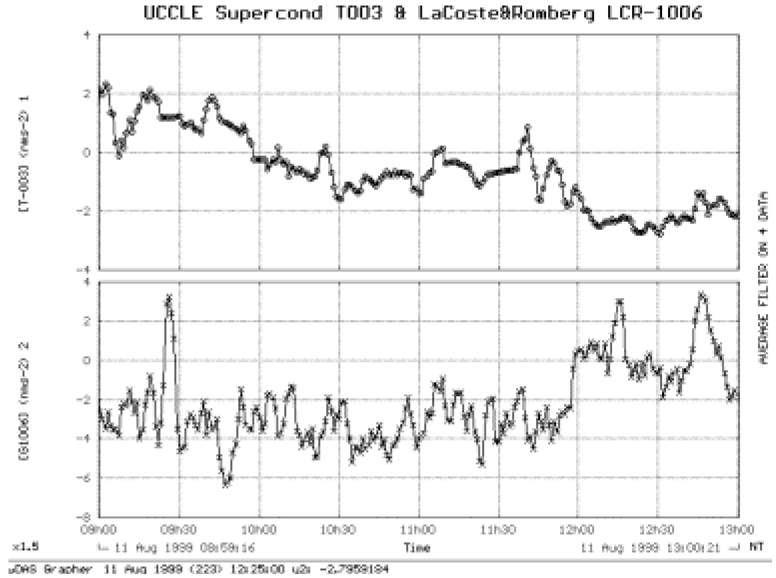


Fig.4 : Gravity changes from 9:00 to 13:00 on August 11,1999 at Uccles station. The two curves show the de-tided records of gravity changes for the gravimeters Super Conducting T-003 (top) and LaCoste&Romberg 1006 (bottom). The first and last contacts at Uccles station are about 9:00 and 12:00 respectively, with totality at 10:30

4.3 the result from Walferdange station

Two Askania gravimeters are used to record the gravity changes at the Walferdange Station during the eclipse on August 11, 1999. Fig. 5 shows the gravity changes recorded by the two Askania gravimeters from 9:30 to 12:22. The first and last contacts at the Walferdange station are about 9:00and 12:22 respectively, with totality at 10:30.All data has been filtered by 2 min. The overall trends of the two curves are same. First they decrease and then they increase. There is no correlation between the detailed gravity changes in them. It seems that for this type of experiment, the precision of Askania gravimeter is about 3μGal. No common abnormal gravity change more than 3μGal can be seen in Fig 5 during the eclipse. So the results from the Walferdange station show that no shielding effects beyond noise level exist.

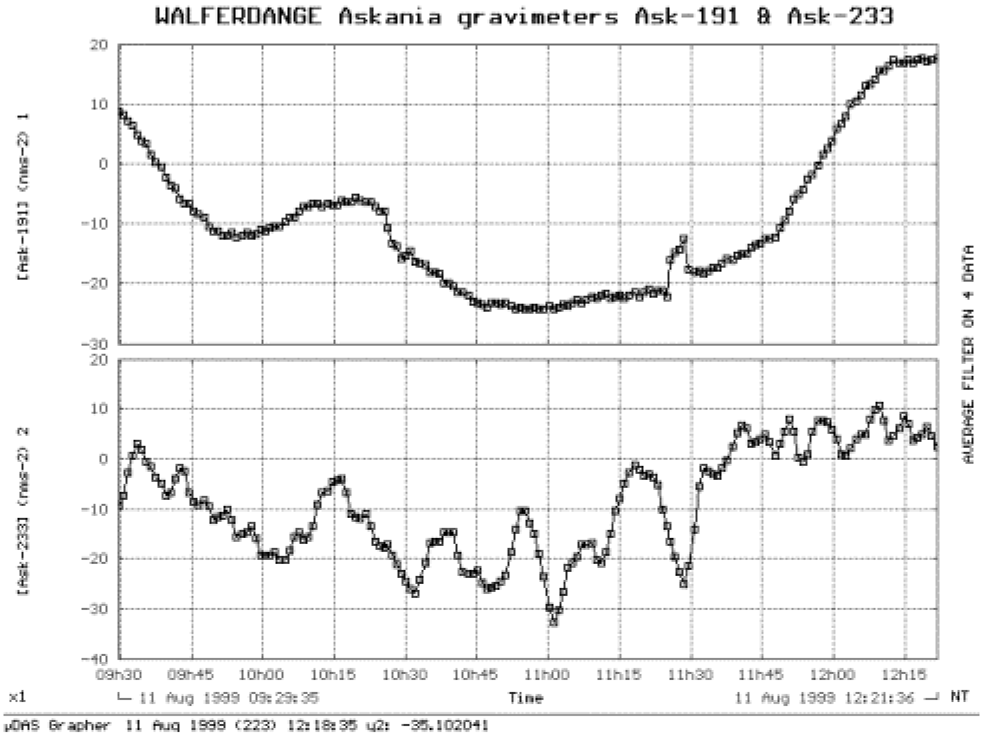


Fig.5: Gravity changes from 9:30 to 12:21 on August 11, 1999 at Walferdange Underground Laboratory of Geodynamics. The two curves show the de-tided records of gravity changes for the gravimeters Askania 191 (top) and Askania 233 (bottom). The first and last contacts at Walferdange station are about 9:00and 12:22 respectively, with totality at 10:30

4.4 the results from the Bondy station

Two LCR gravimeters were used to conduct the gravity measurements during the eclipse at the Bondy station. Fig.6 shows the gravity change from 9:21 to 13:00, 11 August 1999. The first and last contacts at Bondy station are about 9:00and 12:00 respectively, with totality at10:30. All data was filtered by 2 min. The overall tendency of the first curve is decrease. The shape of the second curve is slightly more complicated. At first it decreases, then it increases, then it decreases again, and at last it increases. In the second curve there is a gravity change about 2µGal which is beyond the noise level. As only one gravimeter recorded any gravity change that is beyond noise level, we do not think that the shielding effect has been observed. It is more likely that the abnormal gravity in the second curve is due to a manmade occurrence.

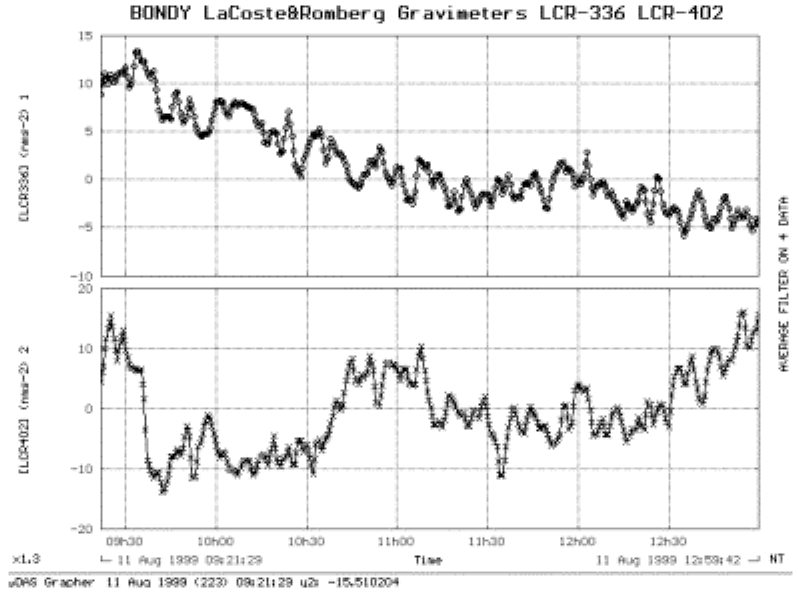


Fig.6: Gravity changes from 9:21 to 13:00 on August 11, 1999 at Bondy station. The two curves show the de-tided records of gravity changes for the gravimeters LaCoste&Romberg 336 (top) and LaCoste&Romberg 402 (bottom). The first and last contacts at Bondy station are about 9:00 and 12:00 respectively, with totality at 10:30.

5. Discussion about the magnitude of any possible shielding effect

According to Newton's Law of Universal Gravitation, the force made by the attraction of the Sun, F_S, acting on a mass, *m,* which is on the surface of the Earth, is given by

$$F_s = Gm\frac{M_s}{b^2} \tag{1}$$

Where G is the gravitational constant, M_S is the Sun's mass and b is the distance from the sun to the mass. The gravitational attraction of the Earth acting on the mass is given by

$$F_e = Gm\frac{M_e}{a^2} \tag{2}$$

where g is the acceleration due to gravity, G and m are the same as those in equation (1), M_e is the mass of the Earth and a is the radius of the Earth.

Let the constant, *g,* be defined as:

$$\gamma = \frac{F_s}{F_e} \tag{3}$$

Substituting equations (1) and (2) into equation (3), gives us

$$\gamma = \frac{M_s a^2}{M_e b^2} \tag{4}$$

Taking the following approximate values:

$$M_s = 2\times10^{30}\,kg$$
$$M_e = 6\times10^{24}\,kg$$
$$a = 6.4\times10^{6}\,m$$
$$b = 150\times10^{9}\,m$$

we obtain a value for g : $g = 6´10^{-4}$ (5)

Re-arranging equation (3) gives us: $F_S = g\,g$.

Taking a value of: $g = 9.8\ m/s^2$, gives us: $F_S = 0.6 Gal$.

If the shielding effect observed by Wang *et al.* (2000), which is about $6\mu Gal$, is the case, its proportion to the attraction force of the Sun (F_S) is about 10^{-5}. With the current level of precision of modern observation techniques, this effect is large enough to be observed.

Such a shielding phenomenon would result in numerous effects, such as perturbations of the moon, the inequality of ocean and earth tides on sides facing and away from the sun, perturbation of satellite's orbits, etc.

Furthermore if a gravitational shielding effect is found to exist, then the question arises whether the Earth itself could act as a shield. For example would the force causing tides, due to the attraction of the moon, be less on the side of the Earth farthest from the moon, as a result of a shielding effect of the Earth itself? Of even more fundamental importance, is whether we would have to redefine the model for the computation of the Earth's gravitational field, to include a factor to represent the shielding effect of the Earth on its own gravitational field.

6. Conclusions

The results presented in this note, in common with most earlier eclipse experiments, show that there is no perceptible change in *g,* above the ambient noise level during totality, as recorded by spring gravimeters. At the Bondy station one spring gravimeter did not record abnormal gravity changes, but the other one did. This is a typical situation, showing the difficulties associated with working with spring gravimeters at the limit of their precision.

In Lalu *et al.* (2001), the records of four superconducting gravimeters permitted us to look for common signal shapes during the eclipse period. We are confident that a common signal pulse of amplitude of at least $2´10^{-9}\ ms^{-2}$, if present, would have been detected. However, no such change was observed, so no change of *g* can be attributed to gravitational shielding from these results.

This contradicts the report by Wang. *et al.* (2000), who observed anomalous changes in *g* at first and last contact in an experiment during the eclipse in 1997 in China. The most likely explanation for the changes in gravimetric readings is an eclipse related effect. An effect probably induced by some electrical occurrence due to the special situation of night conditions occurring during the day.

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