# 5. The Orbits of Planets Violate the UFF

**Abstract:** A recalculation of Kepler's third law with recent data of planets offers a violation of the Universality of Free Fall in order of $1.5 \times 10^{-3}$. Therefore, the equality of the inertial and gravitational mass and the UFF must be invalid basic hypotheses. A revision is appropriate on the fundaments of the physical description.

PACS: 02.40.-k, 04.20.Cv, 04.30.-w

Keywords: Kepler's law, universality of free fall, general principles, gravitational charges, covariant theory of gravity

The three assumptions in physics,

- The equality of inertial mass $m^i$ and gravitational mass $m^g$,
- The Universality of Free Fall (UFF),
- The universality of the gravitational constant,

are anyhow connected together. But a controversy over these three fundamental hypotheses can be observed, see the Internet page of the Eöt-Wash Group, Seattle, Ref. **[1]**. For instance, the relative uncertainty of "Newton's constant" G was set up by the 1998 CODATA decision from $0.13 \times 10^{-3}$ to $1.5 \times 10^{-3}$.

Historically, the basics of the three hypotheses founds on the Kepler's third law, on observations of Galileo Galilei and on the Newton's gravitational law. Here, we want to proof these hypotheses with the motion of planets. Kepler's law

$c_j = R_j^3 / T_j^2$,

must be corrected by a ratio of the planet masses $m_j$ and the sun mass M

$$C_j = R_j^3 / T_j^2 \times M/(M+m_j). \quad (1)$$

Euler's formulation of the equation of motion with Newton's law of gravitational force

$m^i a = - \boldsymbol{G} M^g \; m^g / r^2$ , (2)

leads with the assumption of equality of gravitational mass and inertial mass $m^i$ = $m^g$ to the definition, and with the additional UFF hypothesis, to a constant value of the "Newtonian constant" G. With a distinction of $m^i$ and $m^g$ the quantity $C_j$ would be proportional to the product of the gravitational constant $\boldsymbol{G}$ and the ratio $m^g_j / m^i_j$ . We want to distinguish between $\boldsymbol{G}$ and G, whereby the latter is defined only with the assumed equality of $m^g = m^i$ .

For decades, very precise data of the observed planet orbits are available. The semimajor axis and the sidereal orbit periods are known with an uncertainty of at least $10^{-8}$. The masses of planets and of the sun are much less precisely known, but the assumed accuracy of about $10^{-4}$ is accurate enough for our purpose.

The used data of planets from *Allen's Astrophysical Quantities*, Ref. **[2],** are shown in **Tab. 1**.

| Planet Name | R Semi major Axis [AU] | T Orbit Period [sidereal year] | m Mass $10^{27}$ g |
|---|---|---|---|
| Mercury | 0.38709893 | 0.24084670 | 0.33022 |
| Venus | 0.72333199 | 0.61519726 | 4.86900 |
| Earth | 1.00000011 | 1.00001740 | 5.97420 |
| Mars | 1.52366231 | 1.88084760 | 0.64191 |
| Jupiter | 5.20336301 | 11.86261500 | 1,898.70000 |
| Saturn | 9.53707032 | 29.44749800 | 568.51000 |
| Uranus | 19.19126393 | 84.01684600 | 86.84900 |
| Neptun | 30.06896348 | 164.79132000 | 102.44000 |
| Pluto | 39.48168677 | 247.92065000 | 0.01300 |
| Sun M | | | 1,989,000.00000 |

**Tab. 1** The input planet data used for the calculation of Kepler's third law.

The calculation of the $C_j$ in Eq. (1) and the relative deviation from averaged value $C_0$ are shown in the **Tab. 2** whereby $C_0$ = 1.00042432 $AU^3/(s.y.)^2$

| Planet Name | $c_j = R_j^3/T_j^2$ [$AU^3/(s.y.)^2$] | $C_j = c_j M/(M+m_j)$ [$AU^3/(s.y.)^2$] | $(C_j - C_0)/C_0$ |
|---|---|---|---|
| Mercury | 0.99996434 | 0.99996417 | -0.046% |
| Venus | 0.99996370 | 0.99996125 | -0.046% |
| Earth | 0.99996553 | 0.99996253 | -0.046% |
| Mars | 0.99990551 | 0.99990518 | -0.052% |
| Jupiter | 1.00113237 | 1.00017760 | -0.025% |
| Saturn | 1.00034119 | 1.00005535 | -0.037% |
| Uranus | 1.00147263 | 1.00142890 | 0.100% |
| Neptun | 1.00112131 | 1.00106976 | 0.065% |
| Pluto | 1.00129418 | 1.00129417 | 0.087% |

**Tab. 2** The calculated values $C_j$ of Kepler's third law and their deviations from the averaged value $C_0$.

Without the presentation of an explicit error evaluation, the data is taken form a public data base and they are probably not the best available values, the result in the last row of **Tab. 2**, $(C_j - C_0)/C_0$, is shown with an uncertainty $10^{-5}$ which is much better than the uncertainty of ingoing data. We feel also confident that the uncertainty of $M/(M+m_j) = 1/(1 + m_j/M)$ is better than $10^{-5}$.

The calculation of Eq. (1) shows that the $C_j$ s are not the same constant for all planets and the value of the product $\boldsymbol{G} \times m^g/m^i$ varies in an interval of 0.15%, see also **Fig. 1**.

The deviations of planet orbits from $C_j$ = const must be taken very serious because one of the three basic hypotheses is certainly violated. This statement is very important because the Universality of Free Fall is, in connection with

Kepler's law, one of the basics of the Equivalence Principle (E.P.); see C. Will, Ref **[3]**, and R. H. Dicke, Ref. **[4]**.

The equivalence of the Newton's gravitational law and the Coulomb law on one hand and the mass defect of isotopes on the other hand forces us to adhere to the constancy of ***G*** and to reject the hypothesis $m^g = m^i$. Therefore, the following basic assumption seems to be confirmed by the observed motion of planets:

- The $C_j$ s of planets are composition dependent because $m^g_j/m^i_j$ changes and therefore, the Universality of Free Fall must be violated in the order of 1.5 x $10^{-3}$. The Free Fall must be composition dependent.

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**Fig. 1** The values of Kepler's third law for the planets show the more variation the far a planet from the sun is. The assumption $R^3_j/T^2_j$ x $1/(1+m_j/M)$ = const x $m^g_j/m^i_j$ is justified.

The different mass density - the inner planets have $\rho$ ~5 g/cm$^3$ and the outer ~1 g/cm$^3$ - offers a different composition of planets. But since the contribution to the "masses" comes from the nuclei within the planets, the density is only a hint in connection with a composition dependency of $C_j$. The main effect is caused by the dominant Fe/Ni kernel of the inner planets Mercury, Venus, Earth and Mars. The outer planets are considered to be ice, rock and gaseous objects, whereby the precise chemical element composition within the planets is unknown. The inner four planets have nearly the same value of $C_j$. In comparison to them, the outer planets have much larger deviations. The largest value of $C_j$ has Uranus with 0.15 % above the value of the Mars.

The motion of planets consequently contradicts the UFF hypothesis of Philoponus and Galilei. Our calculated result does not allow the assumption of the UFF.

The result of recalculation of the Kepler's third law relativizes also the recent E.P. test results. The apparent confirmation of the E.P. with about $10^{-13}$ was emphasised by Baessler et al., Ref. **[6].** The planed projects STEP, GALILEO GALILEI (GG), MICROSCOPE, etc., A. Nobili, Ref. **[7]**, have the goal of testing the E.P. up to $10^{-18}$.

In particular, UFF test are very rare. The recent tests of Niebauer, Ref. **[8]**, and of Kuroda, Ref. **[9]**, from ~ 20 cm heights see a 5 x $10^{-12}$ apparent agreement with the UFF. In contradiction to this, the motions of planets show a UFF violation of about 1.5 x $10^{-3}$. This controversy in science can not be accepted and requires further research.

The composition dependency of the relation $m^g/m^i$ has been investigated separately by Szász, Ref. **[5].** Together with the mass number dependency of mass defect gained from isotope masses, G. Audi and A. H. Wapsta, Ref. [12]**,** a microscopic theory of gravity was developed. On basis of the gravitational charge theory the constant ***G*** is connected to an invariant property of elementary particles and $G$ to

$$m^i = m^g (1-\Delta^{MD}), \tag{3}$$

whereby $\Delta^{MD}$ is the relative mass defect of a body. Since $\Delta^{MD}$ is different from element to element and is in the range of several pro mille, the UFF must be violated.

Indeed, a fall experiment of Szász, Ref. **[14]**, observed the UFF violation. Between the elements Li and Al the relative acceleration deviation in a 110 m fall experiment was

$$\Delta a/a = 0.45(1)x10^{-3}. \quad (4)$$

Furthermore, as a consequence of the theory of gravitational charges, a covariant gravitational field was found by Szász, Ref. **[11]**. The covariant gravity has the advantage to lead to the same Riemann's metric in the Minkowski space as electromagnetism.

The covariant theory of gravity is also supported by a recent measurement of the gravity velocity

$$c^{g}/c = 1.06 \pm 0.21, \quad (5)$$

by S. Kopeikin and E. Fomalont, Ref. **[13]**.

Because the concept of gravity and mass is very fundamental in physics, and the new microscopic theory of gravity gives up the equivalency of inertial and gravitational mass and the UFF hypothesis, the other basic hypotheses of physics were also analyzed by Szász, Ref. **[11]** and a fundamental field was found.

The covariant theory of gravitational field avoids the fundamental inconsistency that nature has two different Riemann's metrics in space and time, one for the geometrized gravity and the other for the electromagnetism.

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