New Astronomy 31 (2014) 51–55

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

# Secular perihelion advances of the inner planets and asteroid Icarus

Klaus Wilhelm [a], Bhola N. Dwivedi [b,*]

[a] Max-Planck-Institut für Sonnensystemforschung (MPS), Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany
[b] Dept. of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi 221005, India

ARTICLE INFO

*Article history:*
Received 4 November 2013
Received in revised form 24 January 2014
Accepted 18 February 2014
Available online 6 March 2014

Communicated by G.F. Gilmore

*Keywords:*
Secular perihelion advances
Planets
Asteroid
Solar System
Gravitational-impact model

ABSTRACT

A small effect expected from a recently proposed gravitational impact model (Wilhelm et al., 2013) is used to explain the remaining secular perihelion advance rates of the planets Mercury, Venus, Earth, Mars, and the asteroid (1566) Icarus—after taking into account the disturbances related to Newton's Theory of Gravity. Such a rate was discovered by Le Verrier (1859) for Mercury and calculated by Einstein (1915, 1916) in the framework of his General Theory of Relativity (GTR). Accurate observations are now available for the inner Solar System objects with different orbital parameters. This is important, because it allowed us to demonstrate that the quantitative amount of the deviation from an $1/r$ potential is—under certain conditions—only dependent on the specific mass distribution of the Sun and not on the characteristics of the orbiting objects and their orbits. A displacement of the effective gravitational from the geometric centre of the Sun by about 4400 m towards each object is consistent with the observations and explains the secular perihelion advance rates.



## 1. Introduction

A recently proposed gravitational impact model implies a secular mass increase of all massive bodies fuelled by a decrease in energy of a hypothetical background flux of massless entities—named "quadrupoles". These entities travelling with the speed of light transfer momentum and energy between gravitational centres (Wilhelm et al., 2013). In Section 4.3 of that paper, summarizing past objections to a similar theory of gravitation by Nicolas Fatio de Duillier (Bopp, 1929; Gagnebin, 1949; Zehe, 1983), one of the objections has been discussed as follows:

> It has further been claimed (cf. Drude, 1897) that a third body placed between two gravitating bodies would reduce, or even hinder, the interaction between them. Without an in-depth calculation, it is tenable that this is generally not so in the model described. A third body C, placed between two gravitating bodies A and B, would not significantly affect their interaction for configurations in which the distance between either A and C or B and C is much smaller than the separation from the third body, if the quadrupoles with reduced energy would be emitted on average with spherical symmetry. It is to be noted that the number of quadrupoles will not change, but their energy spectrum will be affected.

The question we want to address in this note is whether the minute effect expected from the gravitational impact model can explain some of the observations in the Solar System indicating the need for modifications of Newton's Theory of Gravity, which is based on a potential exactly proportional to the inverse distance. Body C will cause a kind of re-processing of the quadrupole emission by body A with the consequence that the effective distance between A and B will decrease. In the extended Sun this leads to a deviation from the spherical symmetry of the $1/r$ potential. Prominent examples of such deviations are secular advances of perihelia of Solar System bodies. Hence these advances will be the main subjects of this study.

The "anomalous", i.e., unexpected, secular perihelion advance of Mercury was discovered by Le Verrier (1859) and calculated by Einstein (1915, 1916) in the framework of the GTR, but other solutions had and have been proposed, for instance, an undiscovered inner planet (Vulcan) by Le Verrier; electromagnetic influences and the propagation speed of gravity (Gerber, 1898, 1917), a fast rotation inside the Sun (Roxburgh, 1964), or central-force perturbations (Adkins and McDonnell, 2007), to mention only a few. In the meantime, secular perihelion advances have also been observed for the inner planets. An important aspect is that observations are available for different objects with different orbital parameters, because it has to be demonstrated that the quantitative amount of the deviation from the $1/r$ potential is only dependent on the specific mass distribution of Sun and not on the characteristics of the orbiting objects and their orbits; provided

* Corresponding author. Tel.: +91 9450803939.
*E-mail addresses:* wilhelm@mps.mpg.de (K. Wilhelm), bholadwivedi@gmail.com (B.N. Dwivedi).

http://dx.doi.org/10.1016/j.newast.2014.02.007
1384-1076/

**Table 1**
Orbit characteristics of relevant objects in the Solar System and secular perihelion precession rates.

| Celestial object | Orbital elements[a] J2000 | | Orbital period | Secular perihelion precession rate[b] | Reference |
|---|---|---|---|---|---|
| | $a$/ua | $e$ | $T$/d | $\dot{\omega}$ | |
| Mercury | 0.387 098 93 | 0.205 630 69 | 87.9692 | | NASA Mercury Fact Sheet |
| | | | | (42.978 175) | GTR from Eq. (3) |
| | | | | 38 | Le Verrier (1859) |
| | | | | $43.11 \pm 0.45$ | Duncombe (1956) and Morton (1956) |
| | | | | 43.03 | Clemence (1964) (cf., Nobili and Will, 1986) |
| | | | | $41.9 \pm 0.5$ | Morrison and Ward (1975) |
| | | | | $43.11 \pm 0.21$ | Shapiro et al. (1976) |
| | | | | $42.98 \pm 0.04$ | Nobili and Will (1986) and Will (2006) |
| | | | | $43.13 \pm 0.14$ | Anderson et al. (1992) |
| Venus | 0.723 331 99 | 0.006 773 23 | 224.701 | | NASA Venus Fact Sheet |
| | | | | (8.624 096) | GTR from Eq. (3) |
| | | | | $8.4 \pm 4.8$ | Duncombe (1956) and Morton (1956) |
| | | | | $8.6247 \pm 0.0005$ | Biswas and Mani (2008)[c] |
| Earth | 1.000 000 11 | 0.016 710 22 | 365.256 | | NASA Earth Fact Sheet |
| | | | | (3.838 488) | GTR from Eq. (3) |
| | | | | $5.0 \pm 1.2$ | Duncombe (1956) and Morton (1956) |
| | | | | $3.8387 \pm 0.0004$ | Biswas and Mani (2008)[c] |
| Mars | 1.523 662 31 | 0.093 412 33 | 686.980 | | NASA Mars Fact Sheet |
| | | | | (1.350 858) | GTR from Eq. (3) |
| | | | | 1.35 | Gilvarry (1953) |
| (1566) Icarus | 1.077 941 31 | 0.826 950 44 | 408.781 | | JPL Small-Body Database |
| | | | | (10.061 281) | GTR from Eq. (3) |
| | | | | (10.05) | Gilvarry (1953)[d] |

[a] Mean semi-major axis, $a$, mean eccentricity, $e$. 1 ua = $1.495\,978\,706\,91(6) \times 10^{11}$ m (Bureau International des Poids et Mesures, 2006). The International Astronomical Union (IAU) defined in 2012: 1 AU = $1.495\,978\,707\,00 \times 10^{11}$ m (exact) without relation to the mean Earth–Sun distance.
[b] Secular advance rates in seconds of arc per century as given in the literature. Calculated values in parentheses; the distinction is, however, not always quite clear, because extensive calculations are required before an "observed" value is obtained.
[c] Quoting unpublished results obtained by Pitjeva.
[d] Shapiro et al. (1971) estimated that Icarus observations would give a relative uncertainty in the perihelion advance of $\approx 20\%$ at that time.

that the radius of the Sun, $R_\odot$, is very much smaller than the distance, $r$, to the planetary bodies considered.

## 2. Observational data, fitting procedures and general relativity results

The orbital parameters required, the mean semi-major axis $a$ and the mean eccentricity $e$ as well as the sidereal period $T$, are known with high accuracies and are listed in Table 1. The secular perihelion advance rates $\dot{\omega}$ of Mercury, Venus, Earth, Mars, and (1566) Icarus are not yet directly determined with such accuracy, but for most of them at least two independent observations are available. Their values are listed with uncertainty margins as published in the scientific literature. We take it for granted that all effects resulting from Newtonian gravitation in the Solar System are removed before an observational value is published. Lo et al. (2013) explicitly write that "observed" in this context refers "to the *remaining* discrepancy" after subtraction of other contributions; and Morton (1956) (quoting R.L. Duncombe) defined the observed discrepancies for the advances of Mercury, Venus and Earth: "…in excess of those predicted by all known Newtonian forces." The planetary perturbations lead to an advance for Mercury of more than 500″ per century (cf., e.g., Price and Rush, 1979; Stewart, 2005). In view of this situation, we will not attach great significance to the uncertainty margins.

At this stage it must be mentioned that modern ephemerides of Solar System objects are calculated in a fitting process involving very many observational data. Examples are the series of Jet Propulsion Laboratory Development Ephemeris (JPL DE[number], cf., e.g., Standish and Williams, 2010); the Ephemerides of the Planets and the Moon (EPM[year], Pitjeva, 2001); or Intégrateur Numérique Planétaire de l'Observatoire de Paris (INPOP, Fienga et al., 2005. The latest versions of these ephemerides (Pitjeva and Standish, 2009; Pitjeva and Pitjev, 2013; Fienga et al., 2011, 2013) allow the determination of the perihelion advances with such accuracies that not only the secular advances included in Table 1 and others can be studied, but also putative supplementary precession rates and their potential consequences, in particular, by providing constraints on parameters of the Parameterized Post-Newtonian (PPN) formalism (cf., Lense and Thirring, 1918; Will, 1971; Sanders, 2006; Iorio, 2005, 2007, 2008, 2009, 2012a,b, 2013). The results of these studies are that—with present-day observations—any supplementary rates are extremely small and only for Venus (and Jupiter) do not exceed the measurement uncertainties (Pitjeva and Pitjev, 2013). They have, therefore, been neglected in Table 1.

The planet Mercury is especially relevant with the largest secular advance rate and the most measurements reported, including the first determination by Urbain Le Verrier in 1859. Einstein (1915, 1916) referred to this result and applied the GTR to show that the rate $\epsilon$ in radians per orbit is in agreement with the formula

$$\epsilon = 24\,\pi^3\,\frac{a^2}{T^2\,c_0^2\,(1-e^2)}, \qquad (1)$$

where $c_0 = 299792458$ m/s (exact) is the speed of light (Bureau International des Poids et Mesures, 2006). Taking into account Kepler's third law in the form

$$\frac{a^3}{T^2} = \frac{G_N\,m_\odot}{4\,\pi^2}, \qquad (2)$$

with $G_N = 6.67384 \times 10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$, the Newtonian constant of gravitation (Mohr et al., 2012), and $m_\odot = 1.98853 \times 10^{30}$ kg, the mass of the Sun, Einstein's equation is identical to

$$\epsilon = 6\,\pi\,\frac{G_N\,m_\odot}{a\,c_0^2\,(1-e^2)}, \qquad (3)$$