The influence of the correction of the gravitational constant on the precession of Mercury's perihelion

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Abstract: *This article discusses the effect of the possible changes in the gravitational constant on the precession of Mercury's perihelion. The analysis results show that based on the current more accurate theoretical calculations of relativity, if the correction of the change of the gravitational constant is added, the theoretical calculation results can be improved to a certain extent to make them consistent with the observation results.*

The problem of Mercury's perihelion precession is an important evidence of general relativity. Through general relativity calculations, the abnormal problem of Mercury's perihelion precession can be successfully solved. At present, there are more accurate theoretical calculation data of the influence of the planetary motions of the solar system on Mercury's perihelion, and the influence of relativity theory reaches (42.9779±0.0009)” [1].

In terms of observations, At present, the results extracted by Pireaux from the EPM2001 ephemeris are now more accurate [2, 3], and the observation range reaches 43.0005”~43.0200”.

It can be seen from the above that there is still a certain error between the very high-precision theoretical calculation and the observed value. So where do these errors come from? Perhaps introducing a changing gravitational constant can solve the problem to a certain extent.

According to the analysis of my paper [4] published a few days ago, assuming that the space-time structure of the solar system has a radius of $10^{14}m$, considering that the difference between the orbital radius of the earth and the orbital radius of Mercury is about $\Delta b=9.2\times10^{10}m$, it can be estimated that the value of the gravitational constant at Mercury’s position is

$$G = G_e\left(1+\frac{\Delta b}{b}\right) = G_e\left(1+\frac{9.2\times10^{10}}{10^{14}}\right) \approx G_e(1+9.2\times10^{-4})$$

Where G_e is the gravitational constant measured at the orbital position of the earth, and G is the gravitational constant at the position of Mercury, and b is the radius of the solar system's space-time structure.

The calculation formula of general relativity is [2]:

$$\Delta\omega_{0GR} = \frac{6\pi GM}{a(1-e^2)c^2}$$

Where ω_{0GR} is the precession value of Mercury's perihelion calculated by general relativity. M is the mass of the sun, a is the semi-major axis of Mercury's orbit, e is the eccentricity of Mercury's orbit, and c is the speed of light.

If you consider that the gravitational constant is changing, M, a, e have accurate measurement values, so you can get:

$$\Delta\omega_{0GR} = \frac{6\pi G_e M}{a(1-e^2)c^2}(1 + 9.2 \times 10^{-4})$$

$$\Delta\omega_{0GR} = 42.9779'' \times (1 + 9.2 \times 10^{-4}) = 42.9779'' + 0.0395'' \approx 43.0174''$$

It can be seen that the change of the gravitational constant has an influence of about 0.0395''/century on the precession of Mercury's perihelion, which is in good agreement with the observation result. This also shows that $10^{14}m$ can be used as the lower limit of the solar system's space-time structure radius.

References

[1] Park, Ryan S. , et al. "Precession of Mercury's Perihelion from Ranging to the MESSENGER Spacecraft." Astronomical Journal 153.3(2017):121.

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[3] Pitjeva, E. V. . "Modern Numerical Ephemerides of Planets and the Importance of Ranging Observations for Their Creation." Celestial Mechanics & Dynamical Astronomy 80.3-4(2001):249-271.

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Chinese version

水星近日点进动的引力常数修正

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摘要：本文探讨引力常数可能存在变化的情况下，对水星近日点进动的影响。分析结果表明，在目前比较精确的相对论理论计算值得基础上，如果加上引力常数变化的修正，可以在一定程度上改善理论计算结果，使之与观察结果一致。

水星近日点进动问题是广义相对论的一个重要证据。通过广义相对论的计算，可以成功解决水星近日点进动的异常问题。目前已经有比较精确的太阳系各行星运动对水星近日点影响的理论计算数据，其中相对论的影响达到了 42.9779±0.0009 [1].

而在观察值方面，目前 Pireaux 从 EPM2001 星图中提取出来的结果是现在精度比较高的[2,3]，观察值范围达到 43.0005-43.0200.

从上面可以看出，在非常高精度的理论计算和观察值之间还是存在一定的误差。那么这些误差从何而来，或许引入变化的引力常数可以在一定程度上解决该问题。

按照我前几天发表的论文[4]分析，假设太阳系的时空结构半径为 10^{14}m，考虑到地球的轨道半径与水星的轨道半径差值大约为$\Delta b = 9.2 \times 10^{10} m$，因此可以估算在水星位置的引力常数值为

$$G = G_e\left(1 + \frac{\Delta b}{b}\right) = G_e\left(1 + \frac{9.2 \times 10^{10}}{10^{14}}\right) \approx G_e(1 + 9.2 \times 10^{-4})$$

其中 G_e 为地球轨道位置测量到的引力常数平均值，G 为水星位置的引力常数值，b 为太阳系时空结构的半径。

广义相对论的计算公式是[2]：

$$\Delta\omega_{0GR} = \frac{6\pi GM}{a(1-e^2)c^2}$$

其中ω_{0GR}为广义相对论计算出来的水星近日点进动值。M 为太阳的质量，G 为引力常数，a 为水星轨道半长轴，e 为水星轨道偏心率，c 为光速。

如果考虑到引力常数是变化的，M, a, e 都有精确的测量值，因此可以得到：

$$\Delta\omega_{0GR} = \frac{6\pi G_e M}{a(1-e^2)c^2}(1 + 9.2 \times 10^{-4})$$

$$\Delta\omega_{0GR} = 42.9779'' \times (1 + 9.2 \times 10^{-4}) = 42.9779'' + 0.0395'' \approx 43.0174''$$

可以看出引力常数的变化对水星近日点进动有大约 0.0395’’/century 的影响，计算结果观察结果符合的很好。这也说明 10^{14}m 可以作为太阳系时空结构半径的下限。

参考文献

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