The Pioneer anomaly and the motion of the outer planets of the Solar System

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Pioneer anomaly: unexplained constant and uniform acceleration directed radially towards the Sun of $(8.74 \pm 1.33) \times 10^{-10}$ m s^{-2} (Anderson et al. 1998; 2002) for $r \gtrsim 20$ AU

If it is of gravitational origin, and if the equivalence principle is valid also in the outer regions of Solar System, such an acceleration must also affect the planets located at $r \gtrsim 20$ AU, i.e. Uranus (19.19 AU), Neptune (30.06 AU), Pluto (39.48 AU)

Orbital effects of $\vec{a}_{pio}$ on the planetary motions (Iorio and Giudice 2006)

Keplerian orbital elements

$(a, e, i, \omega, \Omega, M)$

- a: semi-major axis
- ω: perihelion
- M: Mean anomaly

- Secular effects

$$\left\langle \frac{d\omega}{dt} \right\rangle_{Period} = a_{pio} \sqrt{\frac{(1-e^2)a}{GM_\odot}} \longrightarrow \begin{cases} -83.5 \text{ ''}\,cy^{-1} & \text{Uranus !!} \\ -104 \text{ ''}\,cy^{-1} & \text{Neptune !!} \\ -116.2 \text{ ''}\,cy^{-1} & \text{Pluto !!} \end{cases}$$

$$\left\langle \frac{dM}{dt} \right\rangle_{Period} = -3a_{pio} \sqrt{\frac{(1-e^2)a}{GM_\odot}}$$

$$\Delta\dot{\omega}_{URANUS} = \frac{0.5}{cy}'' \pm 1.3'' cy^{-1}$$

(Pitjeva 2006)

- Periodic effects (E eccentric anomaly $M = E - e\sin E$)

$$\Delta a = -\frac{2e\,a_{pio}\,a^3}{GM_\odot}\cos\xi \Big|_{E_0}^{E} \qquad \Delta e = -\frac{(1-e^2)\,a_{pio}\,a^2}{GM_\odot}\cos\xi \Big|_{E_0}^{E}$$

$$\Delta\omega = \frac{\sqrt{1-e^2}\,a_{pio}\,a^2}{GM_\odot}(e\xi - \sin\xi)\Big|_{E_0}^{E}$$

URANUS* ($a = 19.19$ AU $e = 0.047$)

$$\left.\frac{d\omega}{dt}\right|_{Pio} = -83.58 \pm 12.71 \text{ asec/cy}$$

$$\left.\frac{d\omega}{dt}\right|_{meas\ (Pitjeva\ 2006)} = 0.57 \pm 1.30^{*} \text{ asec/cy}$$

* FORMAL accuracy : by re-scaling it by a fator 50 , $\dot{\omega}_{Pio}$ is still ruled out

* For Uranus ($P = 84.07$ yr) we have enough modern observations to cover a full orbital period

NEPTUNE* ($a = 30.06$ AU)

short-period effects

$$\frac{\Delta a}{a} = \frac{2 e A_{pio} a^2}{GM_\odot}(\cos E - \cos E_0) =$$

$$= (-2.2882 \pm 0.3482) \times 10^{-6} (\cos E - \cos E_0)$$

$$\frac{\Delta a}{a} = (1.8282 \pm 0.0002) \times 10^{-6} \quad (JD = 2447763.67)$$

↑ ranging data from Voyager 2 encounter (Anderson et al. 1995) NASA, JPL

* For Neptune ($P = 164$ yr) we have not enough modern observations covering a full orbital period

Brownstein and Moffat (2006) fitted all the presently available data of Pioneer 10/11 getting ($m s^{-2}$)

	Jupiter	Saturn	Uranus
A_{BM}	0.260	3.136	8.660
A^{*}_{meas}	0.001 ± 0.007	-0.134 ± 0.423	0.058 ± 1.338

* From perihelion rates determined by Pitjeva (2006) by re-scaling by 10 the formal errors. For Jupiter, even a re-scaling of 100 would reject the BM model

Right ascension α and declination δ

TRUE, DIRECT OBSERVABLES

- Pitieva (2005) determined the O-C residuals of $\alpha\cos\delta$ and δ of all the outer planets (Jupiter, ..., Pluto): they are uniform, structureless strips enclosed in $\pm 5''$ over almost 100 yr

- An acceleration like a_{pio} would induce on $\alpha\cos\delta$ and δ huge peridic and secular signals of hundreds of arcseconds, totally absent in the residuals