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General formulae for the periapsis shift of a quasi-circular orbit in static spherically symmetric spacetimes and the strong energy condition

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We study the periapsis shift of a quasi-circular orbit in general static spherically symmetric spacetimes. We derive two formulae in full order with respect to the gravitational field, one in terms of the gravitational mass m and the Einstein tensor and the other in terms of the orbital angular velocity and the Einstein tensor. These formulae reproduce the well-known ones for the forward shift in the Schwarzschild spacetime. In a general case, the shift deviates from that in the vacuum spacetime due to a particular combination of the components of the Einstein tensor at the radius r of the orbit. The formulae give a backward shift due to the extended-mass effect in Newtonian gravity. In general relativity, in the weak-field and diffuse regime, the active gravitational mass density, $\rho_A=(\epsilon+p_r+2p_t)/c^2$, plays an important role, where ϵ, p_r and p_t are the energy density, the radial stress and the tangential stress of the matter field, respectively. We show that the shift is backward if ρ_A is beyond a critical value $\rho_c\simeq 2.8\times10^{-15}\,\mathrm{g/cm^3}(m/M_\odot)^2(r/\mathrm{a.u.})^{-4}$, while a forward shift greater than that in the vacuum spacetime instead implies $\rho_A<0$, i.e. the violation of the strong energy condition, and thereby provides evidence for dark energy. We obtain new observational constraints on ρ_A in the Solar System and the Galactic Centre.

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