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GENERAL RELATIVISTIC EFFECTS ON SOLAR SAIL TRAJECTORIES NEAR THE SUN

Abstract

We analyze the effects of general relativity on the relationship between the period and orbital radius of a solar sail in a circular orbit around the sun, as well as on the parabolic and hyperbolic trajectories of a solar sail.

Newtonian gravity and general relativity give exactly the same expression for the period of an object in circular orbit around a static central mass (Kepler's third law). However, when the effects of the curvature of spacetime and solar radiation pressure are considered simultaneously for a solar sail propelled satellite close to the sun, there is a deviation from Kepler's third law. The dynamics for these trajectories is presented. It is shown that solar radiation pressure affects the period of this satellite in two ways: by effectively decreasing the solar mass, thereby increasing the period, and by enhancing the effects of other phenomena by three orders of magnitude or more, rendering some of them detectable. We discuss deviations from Keplerian orbits due to phenomena which may be observed from the motion of solar sail propelled satellites. In particular, we consider deviations in the period of circular orbits due to spacetime curvature of the sun (described by the Schwarzschild metric), frame dragging from the rotation of the sun (described by the large-distance limit of the Kerr metric), the oblateness of the sun, a possible net electric charge of the sun, and a very small positive cosmological constant. We also consider general relativistic effects on non-Keplerian orbits which are outside of the plane of the sun, and how the expression for the pitch angle of the solar sail is altered.

We also consider the effects of general relativity on escape trajectories of solar sails. In order to achieve optimal acceleration for the exploration of the outer solar system during the span of a human lifetime, a solar sail should approach the sun as closely as possible, limited by the maximum temperature that the solar sail can handle. Therefore, the effects of spacetime curvature become important at the beginning of long-range missions. We consider how the effects of spacetime curvature as well as special relativity cause the trajectory of the solar sail to be deflected from its classical Newtonian parabolic or hyperbolic path. Although the angle of deflection is extremely small, this can have a dramatic effect over long distances and should therefore be taken into account at the start of the mission. We also investigate the effects of frame dragging due to the rotation of the sun, which are substantially less than the effects of static spacetime curvature but should still be taken into account when predicting a long-range trajectory.