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## CHANGE IN GENERAL RELATIVISTIC PRECESSION RATES DUE TO LIDOV-KOZAI OSCILLATIONS IN THE SOLAR SYSTEM. A. Sekhar<sup>1</sup>, D. J. Asher<sup>2</sup>, S. C. Werner<sup>1</sup>, J. Vaubaillon<sup>3</sup>, G. Li<sup>4</sup>

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**Introduction:** Two well known phenomena associated with low perihelion distance bodies in orbital dynamics are general relativistic (GR) precession and Lidov-Kozai oscillations.

The accurate prediction of the perihelion shift of Mercury in accord with real observations is one of the significant triumphs of the general theory of relativity developed by Einstein [1]. Past works have looked into the GR precession in perihelion in different types of solar system bodies like planets [2], [3], [4], [5], asteroids [6], comets [7] and meteoroid streams [8], [9], [10]. More recently some works have explored the cases of GR precession in exoplanetary systems [11], [12].

The Lidov-Kozai mechanism was first proposed and derived by [13] and independently by Lidov [14] explaining the periodic exchange between eccentricities  $e$  and inclinations  $i$  thereby increasing or decreasing the perihelion distance  $q$  secularly in the orbiting body.

[15] found that this mechanism is the most efficient way by which asteroidal and cometary orbits could land up in sunskirting or sungrazing orbits. The mechanism has been related to the rapid change in orbits of artificial satellites [14] around the Earth. Past works have shown that the Lidov-Kozai mechanism can lead to a flip in orbits i.e. inclinations switching from prograde to retrograde or vice-versa [15], [16], [17], [18] during the body's secular evolution. The mechanism is known to have an important role in the long term evolution of different classes of small bodies [19], [20] in the context of impact studies [21] due to the Lidov-Kozai cycles in orbital elements which lead to complications in using analytical and numerical techniques [22] to compute impact probabilities from small bodies on planets. More recently there are examples found in the exoplanetary systems [23] which undergo Lidov-Kozai oscillations around the central body thus showing the generality of this phenomenon in any suitable dynamical system.

**Co-existence of GR Precession and Lidov-Kozai Oscillations:** In this work, we were interested to identify bodies evolving in the near future (i.e. thousands of years in this case) into rapid sungrazing and sun colliding phases and undergoing inclination flips, due to Li-

dov-Kozai oscillations and being GR active at the same time. Of all the bodies we checked from the IAU-MPC, and Marsden plus Kracht families from the comet catalogue [24], 96P/Machholz 1 stands out because it shows all these trends in the near future.

The uniqueness of 96P has been reported before in different contexts, its dynamical behaviour having octuple crossing possibilities [25], similar to the case of another periodic comet Machholz, 141P, discussed in [26]. The linkage of the orbit of 96P with orbits of Extreme Trans Neptunian Objects (ETNOs) has been explored by [27]. 96P has been linked with two families of sungrazing comets and two meteoroid streams. Because of its previously established connection [28], [29] with the Marsden and Kracht sungrazers and low  $q$  meteoroid streams like Daytime Arietids (ARI) and Southern Delta Aquariids (SDA), our tests were repeated on all these related objects as well.

Here we find that there are cases where significant GR precession and Lidov-Kozai mechanism can co-exist and can complement each other in an interesting way. Lidov-Kozai leads to secular lowering of  $q$  which in turn leads to a huge increase in GR precession of argument of pericentre. This in turn gives feedback to the Lidov-Kozai mechanism as the  $e$ ,  $i$  and argument of pericentre in Kozai cycles are closely correlated.

In this work, we find real examples of solar system bodies which show the continuum nature between GR precession dominant and Kozai mechanism dominant regimes.

**Results and Discussion:** We have shown that there are bodies in the solar system in which both GR precession and Lidov-Kozai mechanism can co-exist at the same time and for which these effects can be measured and identified using analytical and numerical techniques. Thus there is a continuum of bodies encompassing, firstly GR precession dominant, secondly GR precession plus Lidov-Kozai mechanism co-existing and finally Lidov-Kozai mechanism dominant states which are all permissible in nature. A real solar system body in this intermediate state is identified using compiled observational records from IAU-MPC, Cometary Catalogue, IAU-MDC and performing analytical plus

numerical tests on them. This intermediate state brings up the interesting possibility of drastic changes in GR precession rates (at some points peaking to about 60 times that of Mercury's GR precession) during orbital evolution due to sungrazing and sun colliding phases induced by the Lidov-Kozai mechanism, thus combining both these important effects in a unique and dynamically interesting way. Comet 96P/Machholz 1 stands out as the only real body identified (from our simulations) to be exhibiting these interesting traits, as well as inclination flips, in the near future.

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