Strong gravitational lensing — A probe for extra dimensions and Kalb-Ramond field

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Strong field gravitational lensing in the context of both higher spacetime dimensions and in presence of Kalb-Ramond field have been studied. After developing proper analytical tools to analyze the problem we consider gravitational lensing in three distinct black hole spacetimes — (a) four dimensional black hole in presence of Kalb-Ramond field, (b) brane world black holes with Kalb-Ramond field and finally (c) black hole solution in f(T) gravity. In all the three situations we have depicted the behavior of three observables: the asymptotic position approached by the relativistic images, the angular separation and magnitude difference between the outermost images with others packed inner ones, both numerically and analytically. Difference between these scenarios have also been discussed along with possible observational signatures.

Keywords: Strong Gravitational Lensing; Kalb-Ramond Field

In this talk we will discuss the strong gravitational lensing in the context of both extra dimensions and Kalb-Ramond field. Specifically, we will discuss three situations — (a) Kalb-Ramond field in four spacetime dimensions, (b) Kalb-Ramond field in higher dimensions and its effect on four dimensional brane inherited from the bulk and (c) possible effects of $f(T)$ gravity. In all the three situations we have provided explicit expressions for the three theoretical constructs $u_{\rm ph}$, $\bar{a}$ and $\bar{b}$ respectively. Using these analytical expressions we have estimated values for the three lensing observables (θ_∞, s, r) as well as have presented them graphically. In particular, analytical estimates of these three observables matches with the full numerical results, due to presence of higher order terms in the metric elements, very well. Further to understand possible discord and unity among the three models elaborated on in this work, we have presented collectively the behaviour of the observables in these three scenarios in 1.

It is clear that all the three scenarios are different in one aspect or another. The deflection angle θ_∞ increases for the Kalb-Ramond field in four and higher dimensions but decreases for $f(T)$ gravity. On the other hand, the magnification decreases for Kalb-Ramond field in four dimensions but increases in higher dimensions, while it increases for $f(T)$ gravity. The angular separation shows an opposite effect for Kalb-Ramond field in four and in higher dimensions, while changes from a decreasing to increasing mode in $f(T)$ gravity. Hence the three scenarios offer rich structures and one of the scenario can easily be differentiated from another.

Having summarized the theoretical backdrops with numerical estimates of various observable parameters, let us now elaborate on possible observational signatures of the same. The most promising candidate in this direction seems to be the supermassive black hole at the galactic center, called Sgr A*, which we have used for our numerical estimates as well. Among others the star S2 and S6 orbiting Sgr A*, seems to be the best candidates to act as the source of the lensing and it has also been studied quiet methodically in [1–3]. In particular one may encounter three possible scenarios — (a) One can not distinguish the primary as well as the secondary images, (b) The primary image is well resolved but not the secondary image and (c) Both primary and secondary images are well resolved. It appears that most of the S stars orbiting the central supermassive black hole Sgr A*, the primary image would be resolvable but not the secondaries [4]. Note that the primary observable associated with all these observations is the angular separation between the lensed images and in our notation this corresponds to s. Surprisingly in our framework, the three black hole solutions have three different behaviors for the angular separation. For example, in the case of four-dimensional Kalb-Ramond field the angular separation must be larger compared to the Schwarzschild value while for the higher dimensional Kalb-Ramond field angular separation decreases. On the other hand, for $f(T)$ gravity, the angular separation initially decreases with the torsion parameter but ultimately it starts increasing. Thus in the future if one can arrive at an angular separation which is larger than the Schwarzschild value, then possible existence of higher dimensional Kalb-Ramond field can be ruled out. However as evident from the numerical calculations, the observed angular displacement of the lensed images turns out to be in the range $\sim 20 - 30$ micro arcsecond with a magnification of $6 - 8$ which are well outside the resolutions of the present day astronomical instruments. However the future experiments involving very long baseline interferometry are designed to have an accuracy of $10 - 100$ micro arcsecond along with Milli arcsecond angular resolution imaging [5–10]. In particular it can be demonstrated using the techniques developed in[3,11] that the star S6 orbiting the Sgr A* supermassive black hole will produce a gravitationally lensed image at an angular separation of 30 micro arcsecond by 2062[5].

Thus in the near future, with either event horizon or square kilometer array operational one can directly measure the photon sphere of the sgr A^* supermassive black hole and hence the observables associated with strong gravitational lensing can be experimentally determined. This will lead to possible constraints on the Kalb-Ramond field parameter as well as spacetime torsion due to strong gravitational lensing. In particular with sufficiently better data one might vote in favour of one particular scenario compared to others. For example, if one observes that the magnification of the image increases compared to the Schwarzschild value, then that will definitely bring forward the scenario of Kalb-Ramond field in higher spacetime dimensions. On the other hand, if the magnification decreases but the deflection angle becomes larger than the Schwarzschild value, then Kalb-Ramond field in four spacetime dimensions would a viable candidate. Hence the study of strong gravitational lensing has the potential to address some of the fundamental questions of the universe, e.g., are there extra spacetime dimensions, why spacetime torsion (or, the Kalb-Ramond field) is missing in our nature, etc.? These would be worthwhile to study in the future.

Scenario under consideration	Behaviour of deflection (θ_∞)	Behaviour of separation (s)	Behaviour of magnification (r)
Kalb-Ramond field in four dimensions	Increases	Increases	Decreases
Kalb-Ramond field in higher dimensions	Increases	Decreases	Increases
$f(T)$ gravity	Decreases	Initially decreases then increases	Decreases

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