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The Underlying Mechanisms of Time Dilation in Curved Space-Time

In modern cosmology, the electromagnetic signals coming from moving astronomical objects deliver the exhaustive physical information about the intriguing phenomena going on in the universe. Providing a solid theoretical instruction to analyze these signals is crucial in leading to new and important discoveries. As a diagnostic tool, the Doppler shift measurement is one of the most important spectroscopic measurements made in astronomy. Achieving a complete understanding of the Doppler effect in the curved space-time becomes essential in studying the numerous astrophysical phenomena and some progress has been made by many researchers in the past. For the Doppler effect in curved space-time, one needs to solve the wave equations of quantum field theory (QFT) to examine the evolution of waves during the propagations. Besides, since atoms usually are used as emitters or receivers of waves, the interactions between the propagating waves with the atoms whose energy levels might be shifted due to the motion in curved space-time need to be well understood. Because of these reasons, the combination of general relativity with QFT to investigate the Doppler effect becomes a necessity, and some new features that have not been considered in previous works may arise from it.

We investigate the influence of space-time curvature on two atoms located far away from each other such that the metric value inside the atoms can be taken as constants. In order to analyse the behaviour of these atoms, we introduce a new coordinate system which maintains the local metric the same as that in the original coordinate , and such Coordinate Transformation which Maintains the Local Metric is abbreviated as CTMLM throughout this paper. As a result of CTMLM, the quantum states of the atoms in two different coordinate systems take the same mathematical forms, therefore, CTMLM can be proved to be one type of CTMPC. Meanwhile, as applications of CTMLM, the time dilation and Doppler effect with an arbitrary relative velocity in curved space-time will be studied.

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