General Relativity and Quantum Cosmology

Relative velocities for radial motion in expanding Robertson-Walker spacetimes

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The expansion of space, and other geometric properties of cosmological models, can be studied using geometrically defined notions of relative velocity. In this paper, we consider test particles undergoing radial motion relative to comoving (geodesic) observers in Robertson-Walker cosmologies, whose scale factors are increasing functions of cosmological time. Analytical and numerical comparisons of the Fermi, kinematic, astrometric, and the spectroscopic relative velocities of test particles are given under general circumstances. Examples include recessional comoving test particles in the de Sitter universe, the radiation-dominated universe, and the matter-dominated universe. Three distinct coordinate charts, each with different notions of simultaneity, are employed in the calculations. It is shown that the astrometric relative velocity of a radially receding test particle cannot be superluminal in any expanding Robertson-Walker spacetime. However, necessary and sufficient conditions are given for the existence of superluminal Fermi speeds, and it is shown how the four concepts of relative velocity determine geometric properties of the spacetime.

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