Light rays propagating around a compact gravitating object in a dispersive and refractive medium have been frequently studied analytically during recent years. Their description in the geometrical optics approximation is very appropriately performed in the Hamiltonian formalism. Despite the apparent simplifications, systems typically analysed in the field are rather simple. The thesis presents results based on this formalism aimed to extend the current typical applications. First, a general axially symmetric object is considered and a generalized Carter constant for cold plasma is derived. Next, general expressions characterizing the basic properties of light propagation, such as the photon region or the deflection angle, are derived. Ray trajectories in the vicinity of objects described both by the Kerr and Hartle-Thorne metrics are discussed. A refractive and dispersive medium characterised either by radial or rotational motion is considered and the deflection angles around a spherically symmetric object are calculated. A perturbative approach to the moving medium is further presented in two distinctive ways. Light rays defined by their impact parameters are also studied in terms of the allowed regions around a Kerr black hole.