Astrophysics > Earth and Planetary Astrophysics

Gravitationally Induced Density Wake of a Circularly Orbiting Object As an Interpretative Framework of Ubiquitous Spirals and Arcs

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An orbiting object in a gas rich environment creates a gravitational density wake containing information about the object and its orbit. Using linear perturbation theory, we analyze the observable properties of the gravitational wake due to the object circularly moving in a static homogeneous gaseous medium, in order to derive the Bondi accretion radius r_B, the orbital distance r_p, and the Mach number of the object. Supersonic motion, producing a wake of spiral-onion shell structure, exhibits a single-armed Archimedes spiral and two-centered circular arcs with respect to the line of sight. The pitch angle, arm width, and spacing of the spiral pattern are entirely determined by the orbital distance r_p and Mach number of the object. The arm-interarm density contrast is proportional to the Bondi accretion radius, decreasing as a function of distance with a power index of -1. The background density distribution is globally changed from initially uniform to centrally concentrated. The vertical structure of the wake is manifested as circular arcs with the center at the object location. The angular extent of the arcs is determined by the Mach number of the object motion. Diagnostic probes of nonlinear wakes such as a detached bow shock, an absence of the definite inner arm boundary, the presence of turbulent low density eddies, and elongated shapes of arcs are explained in the extension of the linear analysis. The density enhancement at the center is always r_B/r_p independent of the nonlinearity, suggesting that massive objects can substantially modify the background distribution. These detailed understanding of the wake characteristics will provide an interpretative framework for both further theoretical works under more complicated situations and future observations to detect the gravitational wakes of hidden objects.

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