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Proto-atmosphere Accretion on Planets with Eccentric Orbits

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Abstract

Protoplanets are believed to form before gas dissipates in the protoplanetary disk and are likely to capture proto-atmospheres from the nebula gas [1]. Such hydrogen-rich atmospheres have been detected and characterized in exoplanetary systems (e.g. low-density super Earths and mini Neptunes) [2, 3]. The accretion process and the structure of the proto-atmosphere is subject to the disk environment such as the evaporation of nebula gas, the eccentricity of the planet's orbit and the planet mass, etc. In this study, we used the hydrodynamic code PLUTO [4] and the radiation transport module MAKEMAKE [5] to model the accretion event of H_2-dominated atmospheres. We established a 2-D radiative accretion model with sophisticated opacity treatment to simulate protoplanets capturing atmospheres on eccentric orbits. We revealed astonishing recycling behaviors of gas flow around the planet, forming an asymmetric but stable atmosphere inside the bow shock structure. We also quantitatively explored how such primordial atmospheres are sensitive to the relative velocity of the planet and disk gas, the planet mass, disk gas density/pressure and the overall orbital evolution. A supersonic environment turns out to be favorable for planets to keep an early stable atmosphere, rather than harmful. The denser the disk, the bigger the planet and the smaller the Mach number (still supersonic), the thicker the atmosphere can be retained. The orbital evolution of the planet can also insert a forced oscillation on the atmosphere properties. Our study provides important insights in understanding how planet migration and orbital eccentricity affect the formation and evolution of proto-atmospheres for Earth-size planets. The problem of proto-atmosphere accretion is fundamental to science topics including the nebula origin of terrestrial water and other volatiles, the supply of Earth's noble gases, etc. Understanding how the proto-atmospheres could influence or even create the current terrestrial planetary environments in the solar system also has general significance to the study of exoplanet geochemistry and habitability.

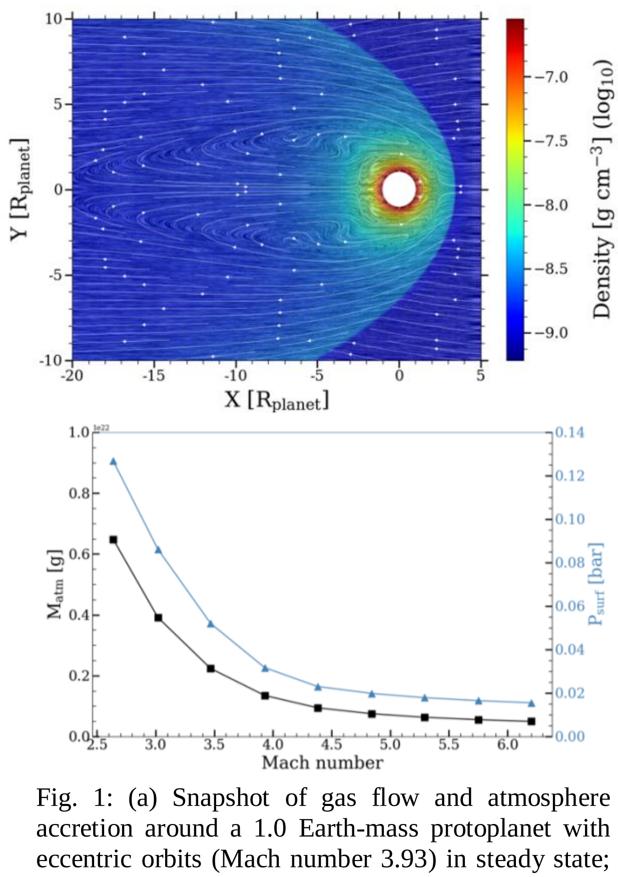

Fig. 1: (a) Snapshot of gas flow and atmosphere accretion around a 1.0 Earth-mass protoplanet with eccentric orbits (Mach number 3.93) in steady state; (b) Accreted atmosphere mass and planet surface pressures with different Mach numbers/relative velocity between planet and disk gas.

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