The stability of hydrogen-rich atmospheres of Earth-like planets

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Understanding hydrogen escape is essential to understanding the limits to habitability, both for liquid water where the Sun is bright, but also to assess the true potential of H2 as a greenhouse gas where the Sun is faint. Hydrogen-rich primary atmospheres of Earth-like planets can result either from gravitational capture of solar nebular gases (with helium), or from impact shock processing of a wide variety of volatile-rich planetesimals (typically accompanied by H2O, CO2, and under the right circumstances, CH4). Most studies of hydrogen escape from planets focus on determining how fast the hydrogen escapes. In general this requires solving hydrodynamic equations that take into account the acceleration of hydrogen through a critical transonic point and an energy budget that should include radiative heating and cooling, thermal conduction, the work done in lifting the hydrogen against gravity, and the residual heat carried by the hydrogen as it leaves. But for planets from which hydrogen escape is modest or insignificant, the atmosphere can be approximated as hydrostatic, which is much simpler, and for which a relatively full-featured treatment of radiative cooling by embedded molecules, atoms, and ions such as CO2 and H3+ is straightforward. Previous work has overlooked the fact that the H2 molecule is extremely efficient at exciting non-LTE CO2 15 micron emission, and thus that radiative cooling can be markedly more efficient when H2 is abundant. We map out the region of phase space in which terrestrial planets keep hydrogen-rich atmospheres, which is what we actually want to know for habitability. We will use this framework to reassess Tian et al's hypothesis that H2-rich atmospheres may have been rather long-lived on Earth itself. Finally, we will address the empirical observation that rocky planets with thin or negligible atmospheres are rarely or never bigger than 1.6 Earth radii.