Loss of planetary atmospheres to space

The atmosphere of a planet can respond to heating from stellar radiation, and (less commonly significant) from the planet's interior, by either thermally radiating all that energy back into space, its' temperature increasing or losing matter to space (atmospheric escape). The first case must dominate for objects in long-lasting states as the others result in atmospheric evolution. The escape of atmospheres is extremely important to understanding how bodies come to have their present atmosphere, or no atmosphere at all.

The mechanisms for atmospheric escape can be categorised in various ways, and the choice is always a trade-off between respecting the current literature and the most sensical framework. Thermal escape occurs in two forms or approximations: Jeans escape and hydrodynamic escape. Both preferentially select for lighter molecules and require heating in the collisional zone of the atmosphere i.e. below the exobase altitude, where mean free path is roughly equal to scale height. Jeans escape is the classic story, where those particles in the tail end of the Maxwellian velocity distribution have enough kinetic energy to escape the gravitational potential-well and if they are at the exobase, are then able to move ballistically out through the exosphere, escaping. Jeans' escape is thought to have been significant in the evolution of the atmospheres of the early terrestrial planets and accounts for a fraction of the current hydrogen-loss from Earth, Mars and Titan. Suprathermal (often called non-thermal) escape relies on strong deviations from the Maxwellian due to chemical reactions or ionic interactions. An atmosphere can also be eroded by solar wind or large impacts.

Hydrodynamic escape is a mean outward escaping flow of gas, which acts like a collisional fluid and is driven by the pressure gradient force. As an analogy, i*magine you are a blowing up a balloon, but the wall of the balloon is permeable and as it gets bigger, more and more gas escapes through it.* This form of escape is more efficient than Jeans as no energy is wasted on molecular motion towards the planet, and the energy is taken up directly by the escaping molecules rather than contributing to the overall distribution of velocities. Hydrodynamic escape is most effective for hydrogen-rich atmospheres and is powerful enough to change the composition of a planetary atmosphere irreversibly. Current research hypothesises that Venus may have lost an ocean of water, and that Pluto may currently be losing nitrogen, both via hydrodynamic escape.

Building on previous research, I built a computational model of a hydrodynamically escaping planetary atmosphere, which I have applied to a few different planets and moons, and am currently applying to many more. The research is ongoing; I am currently writing up a thesis-style report on the work.

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