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Analysis of the effect of the radiation pressure on planetary exospheres : application to Earth, Mars, Titan and hot Jupiters

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Because of rare collisions, the motion of light species (H, H2) in the planetary exospheres is essentially determined by the external forces: the gravitation from the planet and the radiation pressure, ... Currently, the only analytical model used to model exospheric neutral density profiles is the well-known Chamberlain model which takes into account only the gravity. In this work and in the same way as Chamberlain, we solve rigorously and analytically, based on the Hamiltonian mechanics and Liouville theorem, the additional effect of the radiation pressure in particular for hydrogen (the model works for any species sensitive to the radiation pressure) on the structure of the exosphere and on the density profiles of ballistic particles. This approach was initially developed by Bishop and Chamberlain (1989) only in the Sun-planet direction. We extend it here to the whole exosphere with a 2D model. Also, we determine analytically the escape flux on the dayside at SZA=0, which can be compared with the Jeans' escape flux.

We thus show that the radiation pressure induces :
1. strong density asymmetries at high altitudes in the planetary exospheres, leading to the phenomenon of geotail at Earth for example
2. the natural existence of an external limit (or exopause) for the exosphere, whose location is analytically determined
3. an increase of the exospheric densities compared with Chamberlain profiles without radiation pressure (e.g. up to +150% at 5 Martian radius)
4. a significant increase of the thermal escape flux (up to 30/35% for Earth/Mars today), until a «blow-off » regime with a constant escape flux for an extreme radiation pressure. The influence of the radiation pressure on the escape flux may thus bring conditions on the size of primary atmospheres, because of a strong radiation pressure in the Sun's young years.

Finally, we show that this model may be applied to exoplanets, in particular to the hot Jupiters that are also subject to additional effects: centrifugal force and stellar gravity. We show the influence of the radiation pressure on the equipotentials of the Circular Restricted Three Body Problem. We also demonstrate that the hot Jupiter HD 209458b is actually in a blow-off regime induced by the radiation pressure, which allows us to propose an alternative scenario for the evolution of its atmosphere.