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Close-in sub-Neptunes reveal the past rotation history of their host stars: atmospheric evolution of planets in the HD3167 and K2-32 planetary systems

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Planet atmospheric escape induced by high-energy stellar irradiation is known to be a key parameter shaping the structure and evolution of planetary atmospheres. Therefore the present-day properties of a planetary atmosphere are intimately connected with the amount of stellar flux received by a planet during its lifetime, thus with the evolutionary path of its host star.

Recently we have assembled a large grid of upper planetary atmosphere models covering the planets in a size range from Earth to twice Neptune orbiting early M- to late F-type main-sequence stars at distances from roughly habitable zone (300 K) to the close-in orbits corresponding to 2000 K. The grid consists of about 7000 points and provides fast estimations of the atmospheric escape rates for any planetary parameters within its range. To further decrease the calculation time we developed the analytical approximation based on the grid, which relates the atmospheric escape rates to the planetary basic parameters (mass, radius, equilibrium temperature, orbital separation, and stellar insolation level).

Using those results, we developed a model to track the evolution of a planet as a function of the stellar flux evolution history. We combine this model with a Bayesian framework to infer the stellar flux evolution history, constrained by the present-time mass and radius of its planets. We find that the ideal objects for this type of study are sub-Neptune planets orbiting close to their stars, as they are highly affected by atmospheric escape, and yet, can often retain a significant fraction of their primordial hydrogen-dominated atmospheres.

We present the modelling scheme and its application to the analysis of HD3167 and K2-32 planetary systems, finding that their most probable irradiation levels at the age of 100 Myr were medium (in a range of 30-130 of solar flux) and low (below 0.5 of the solar flux), respectively. Finally, we show that for multi-planet systems, our framework enables to put constraints on poorly known properties of individual planets.