CUTE: The Colorado Ultraviolet Transit Experiment

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Exoplanets in short-period orbits provide a unique opportunity to observe phenomena critical to the development and evolution of our own solar system, including atmospheric escape, interaction with the host star, and the potential to study exoplanetary magnetism. At present, the theories explaining upper atmosphere observations exceed the number of relevant transit observations because these processes cannot be observed in broad-band visible/NIR light curves. Owing to their large sizes and short-periods, the physics of atmospheric mass loss can be studied on hot Jovian and Neptunian-mass planets by a dedicated small instrument operating at ultraviolet wavelengths, such as the Colorado Ultraviolet Transit Experiment (CUTE). CUTE will monitor planetary transits at near-ultraviolet wavelengths to study the physics of atmospheric escape and possibly detect the presence of magnetic fields on exoplanets.

1 CUTE's science

Short-period (i.e., < 5 days) extra-solar planets (exoplanets) provide a unique window on a number of phenomena affecting the evolution of planets, such as atmospheric escape, star-planet interactions, and the presence of planetary magnetic fields. Short-period planets possess inflated atmospheres that may extend up to several planetary radii. High-energy stellar radiation (i.e., X-rays and Extreme Ultraviolet radiation), deposited in the upper atmosphere of planets, causes the thermosphere to expand. As a consequence, the atmosphere may reach the planet's Roche lobe, where it may escape to space and further interact with the stellar wind.

Escape processes, the upper atmosphere of planets, and its interactions with the host star can be best studied observationally at ultraviolet wavelengths (at longer wavelengths the optical depth of the escaping material is low). Ultraviolet transit observations allow one to unveil the fate of the gas lost by the planet, infer the structure and composition of the upper atmosphere, and gather information about the characteristics of the host star (e.g., high-energy fluxes and stellar wind). The study of exoplanets, in particular of the structure and evolution of their atmospheres, can provide an important laboratory to better understand the processes that shaped the atmospheres of planets within our solar system.

So far, thorough ultraviolet observations have been published for three hot-Jupiters (HD 209458b, HD 189733b, WASP-12b) and a warm Neptune (GJ 436b). The observations, conducted at far-ultraviolet (FUV; 1200 – 1700 Å) and near-ultraviolet (NUV; 1700 – 3200 Å) wavelengths, showed that these planets indeed host extended, escaping atmospheres. The observations led also to the detection of metals (O, N, Si, Mg, and Fe) in the upper atmosphere, indicating that these species are escaping along with the lighter hydrogen (e.g., Vidal-Madjar et al., 2003, 2004, 2013; Fossati et al., 2010; Linsky et al., 2010; Haswell et al., 2012; Ballester & Ben-Jaffel, 2015; Ehrenreich et al., 2015; Bourrier et al., 2016). Most of the modelling performed to estimate the mass-loss rates of these planets agreed on values of the order of $10^{10}\,\mathrm{g\,s^{-1}}$ (e.g., Yelle, 2004; García Muñoz, 2007; Murray-Clay et al., 2009; Ehrenreich & Désert, 2011; Koskinen et al., 2013; Khodachenko et al., 2015), which are much higher than what is observed today for the inner solar system planets such as Mars for which the current mass-loss rate is of the order of $100\,\mathrm{g\,s^{-1}}$ (Slipski & Jakosky, 2016).

The ultraviolet observations of these systems have also led to the detection of late-egresses, modelled as comet-like tails of atmospheric material, and early-ingresses, that have been alternatively interpreted as the presence of bow-shocks ahead of the planet's orbital motion supported by either the planetary magnetic field (Vidotto et al., 2010) or by the expanding planetary atmosphere (Bisikalo et al., 2013). Many of these phenomena exhibit temporal variabilities that can only be investigated by monitoring several contiguous transits.

At present, the theories explaining the available observations greatly exceed the number of relevant transit observations because these processes need to be observed from space and require monitoring capabilities. Thanks to the large sizes and short-periods of close-in Jupiter- and Neptune-mass planets, these phenomena can be studied with relatively small space telescopes and instruments operating at NUV wavelengths, such as the Colorado Ultraviolet Transit Experiment (CUTE), which is a 6U cubesat mission proposed to NASA and currently under review. CUTE will monitor 10 – 20 transits of approximately a dozen planets at NUV wavelengths with the aim of greatly increasing our understanding of the physics and temporal variability of atmospheric escape, possibly leading also to the detection of exoplanetary magnetic fields.

References

Ballester, G. E., Ben-Jaffel, L., *Re-visit of HST FUV Observations of the Hot-Jupiter System HD 209458: No Si III Detection and the Need for COS Transit Observations*, ApJ **804**, 116 (2015), 1503.01621

Bisikalo, D., et al., *Three-dimensional Gas Dynamic Simulation of the Interaction between the Exoplanet WASP-12b and its Host Star*, ApJ **764**, 19 (2013), 1212.2779

Bourrier, V., et al., *An evaporating planet in the wind: stellar wind interactions with the radiatively braked exosphere of GJ 436 b*, A&A **591**, A121 (2016), 1605.07973

Ehrenreich, D., Désert, J.-M., *Mass-loss rates for transiting exoplanets*, A&A **529**, A136 (2011), 1103.0011

Ehrenreich, D., et al., *A giant comet-like cloud of hydrogen escaping the warm Neptune-mass exoplanet GJ 436b*, Nature **522**, 459 (2015), 1506.07541

Fossati, L., et al., *Metals in the Exosphere of the Highly Irradiated Planet WASP-12b*, ApJ **714**, L222 (2010), 1005.3656

García Muñoz, A., *Physical and chemical aeronomy of HD 209458b*, Planet. Space Sci. **55**, 1426 (2007)

Haswell, C. A., et al., *Near-ultraviolet Absorption, Chromospheric Activity, and Star-Planet Interactions in the WASP-12 system*, ApJ **760**, 79 (2012), 1301.1860

Khodachenko, M. L., Shaikhislamov, I. F., Lammer, H., Prokopov, P. A., *Atmosphere Expansion and Mass Loss of Close-orbit Giant Exoplanets Heated by Stellar XUV. II. Effects of Planetary Magnetic Field; Structuring of Inner Magnetosphere*, ApJ **813**, 50 (2015)

Koskinen, T. T., Yelle, R. V., Harris, M. J., Lavvas, P., *The escape of heavy atoms from the ionosphere of HD 209458b. II. Interpretation of the observations*, Icarus **226**, 1695 (2013), 1210.1543

Linsky, J. L., et al., *Observations of Mass Loss from the Transiting Exoplanet HD 209458b*, ApJ **717**, 1291 (2010), 1005.1633

Murray-Clay, R. A., Chiang, E. I., Murray, N., *Atmospheric Escape From Hot Jupiters*, ApJ **693**, 23 (2009), 0811.0006

Slipski, M., Jakosky, B. M., *Argon isotopes as tracers for martian atmospheric loss*, Icarus **272**, 212 (2016)

Vidal-Madjar, A., et al., *An extended upper atmosphere around the extrasolar planet HD209458b*, Nature **422**, 143 (2003)

Vidal-Madjar, A., et al., *Detection of Oxygen and Carbon in the Hydrodynamically Escaping Atmosphere of the Extrasolar Planet HD 209458b*, ApJ **604**, L69 (2004), astro-ph/0401457

Vidal-Madjar, A., et al., *Magnesium in the atmosphere of the planet HD 209458 b: observations of the thermosphere-exosphere transition region*, A&A **560**, A54 (2013), 1310.8104

Vidotto, A. A., Jardine, M., Helling, C., *Early UV Ingress in WASP-12b: Measuring Planetary Magnetic Fields*, ApJ **722**, L168 (2010), 1009.5947

Yelle, R. V., *Aeronomy of extra-solar giant planets at small orbital distances*, Icarus **170**, 167 (2004)