Temporal variations in the evaporating atmosphere of the exoplanet HD189733b

Abstract

We present Lyman-α transit observations of HD189733b at two different epochs that show, for the first time, that there are significant temporal variations in the physical conditions of an evaporating atmosphere. While atmospheric hydrogen is not detected in the first epoch observations, it is observed at the second epoch, producing transit absorption depths of 14.4±3.6% between velocities of -230 to -140 km s^{-1}. These large velocities cannot arise from radiation pressure alone and require an additional acceleration mechanism, such as interactions with stellar wind protons. The observed changes within the upper atmosphere can be caused either by variations in the stellar wind properties, or by variations in the stellar energy input to the planetary escaping gas, as suggested by simultaneous X-ray observations.

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Observations

We observed two transits of HD189733b on 6 April 2010 and 7 September 2011 with STIS onboard HST. The transit signature of the planetary atmosphere appears as an excess absorption when comparing spectra taken during transit to those taken before the transit event .

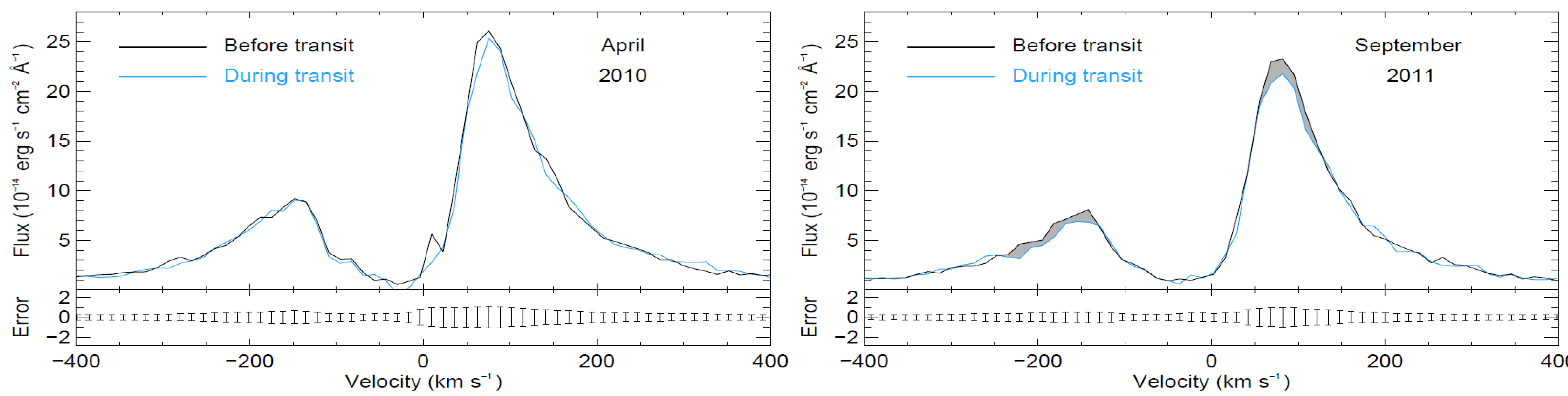

Fig. 1. Lyman-α emission line of HD189733b for both visits. Spectra obtained before (black) and during the transits (blue) are displayed as a function of radial velocity relative to the star. While no transit signatures are detected in 2010, two absorption regions are detected at more than 3 σ during the transit of 2011 (gray zones). They are seen at the top of the red wing around +80 km s^{-1} and, most significantly, in the blue wing with a 100 km s^{-1} wide absorption around -200 km s^{-1}.

Transit depths	2007 – 2008 (ACS) Non λ resolved	2010 (STIS) λ resolved	2011 (STIS) λ resolved
Planetary disk occultation	2.4%	2.4%	2.4%
Whole Lyman-α line	5.05±0.75%	2.9±1.4%	5.0±1.3%
-230 to -140 km s^{-1}		0.5±3.8%	**14.4±3.6%**
60 to 110 km s^{-1}		5.8±2.6%	7.7±2.7%

Detection of temporal variations in the evaporating atmosphere

The 2010 observations do not show any atmospheric transit signature, beyond the 2.4% absorption by the planet itself (Désert et al. 2009; Sing et al. 2011). This situation is different in 2011, with an excess absorption in the whole line consistent with the HST/ACS observations of 2007-2008 (Lecavelier des Etangs et al. 2010). The line profile shows in 2011 **two deep absorption regions** at specific wavelength intervals during the transit, in the blue (4 σ detection) and the red wing (3 σ detection). The **false positive probability** that noise be the source of these signatures is respectively **3.6%** and 24.6%. We conclude that there are **significant temporal variations** of the physical conditions within the extended exosphere of this extrasolar planet (Fig. 2).

For HD209458b, the spectral range of the excess absorption is well explained by the **stellar radiation pressure** (Lecavelier des Etangs et al. 2008). For HD189733b, an additional acceleration mechanism is needed to explain the observed high velocities. We developed a numerical Monte-Carlo simulation of the hydrogen atom dynamics (Fig. 4 - details in Bourrier et al. in preparation). In this N-body simulation, hydrogen atoms are released from the upper atmosphere and rapidly accelerated by the radiation pressure up to 120 km s^{-1} and then to higher velocities by **charge exchange with protons from the stellar wind** (Holström et al. 2008; Ekenbäck et al. 2010). We find that the observations are well fit with an escape rate of about 10^9 g s^{-1} and a stellar wind with temperature T~10^5 K, density n~3×10^3 cm^{-3}, and velocity v~190 km s^{-1} (Fig. 3). The EUV flux controlling the atomic hydrogen ionizing timescale should be around 5 times the solar value to explain the moderate absorption observed after the transit of the planet (Fig. 2).

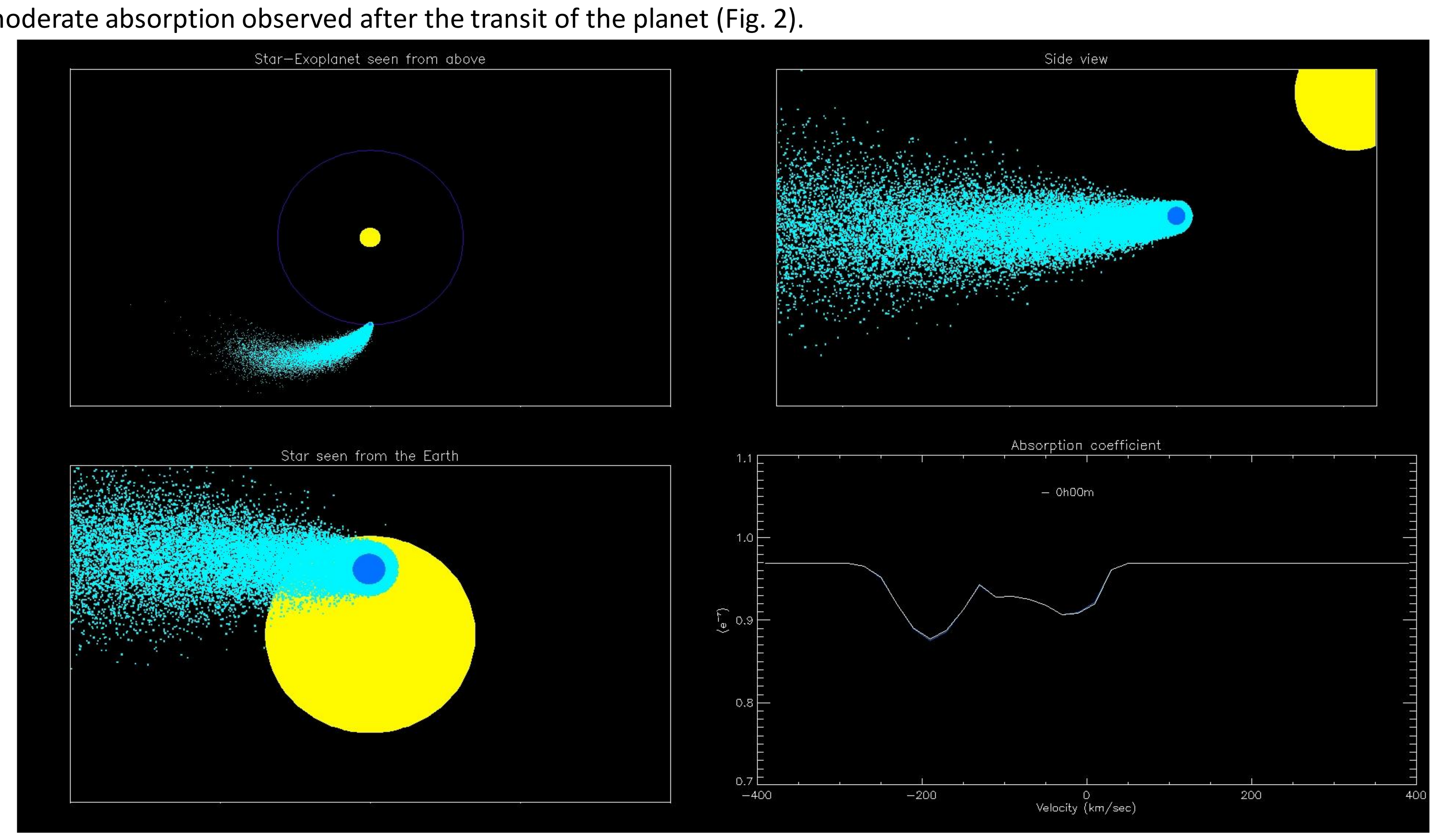

Fig. 4. Views of the planetary system from the N–body model, with escaping hydrogen and simulated absorption

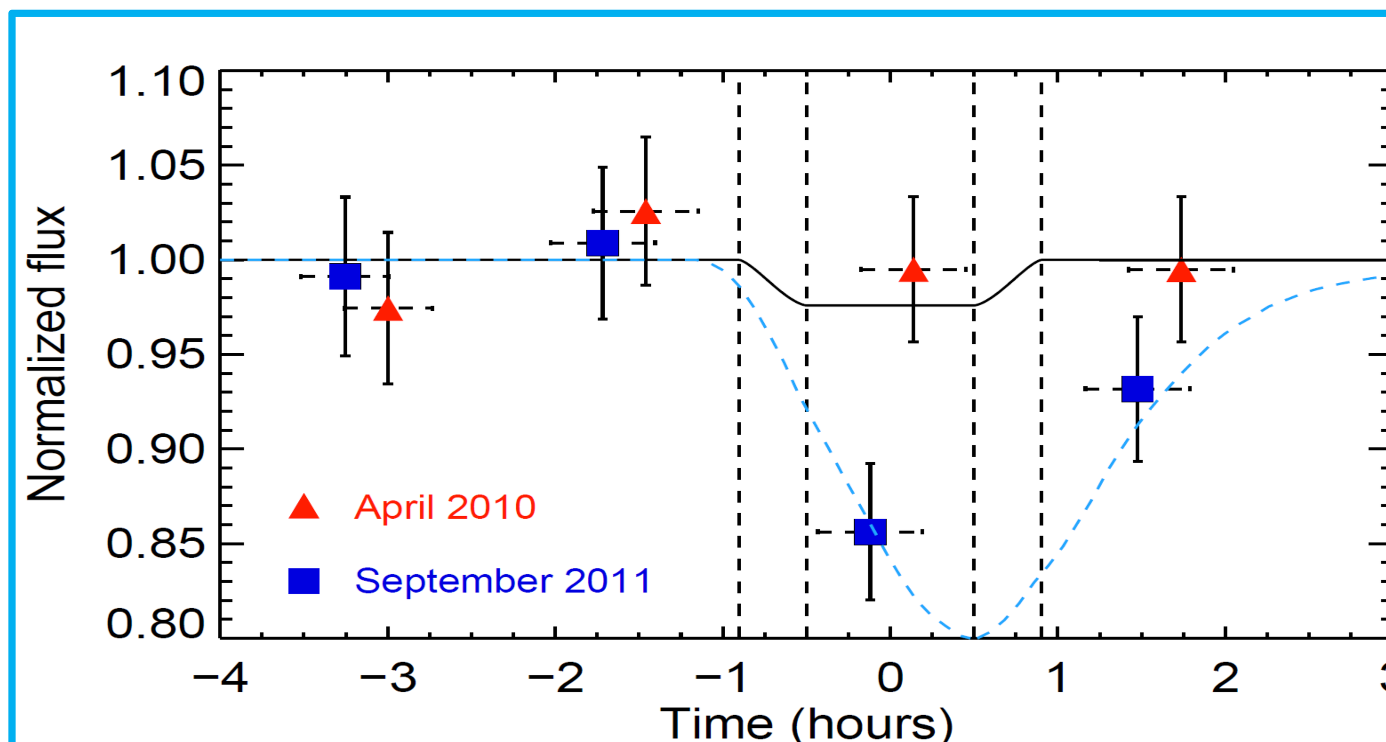

Fig. 2. Plot of the flux between -230 and -140 km s^{-1} as a function of time relative to the center of the planetary transit. Vertical dashed lines show the beginning and end of ingress and egress of the transit. The red triangular symbols are for the 2010 observations, while the blue square symbols correspond to observations of 2011. Horizontal error bars show the duration of the exposures in each HST orbit. The light curve of the planet's transit at optical wavelengths is displayed as a solid black line. The blue dashed line shows the calculated flux using the best fit numerical simulation.

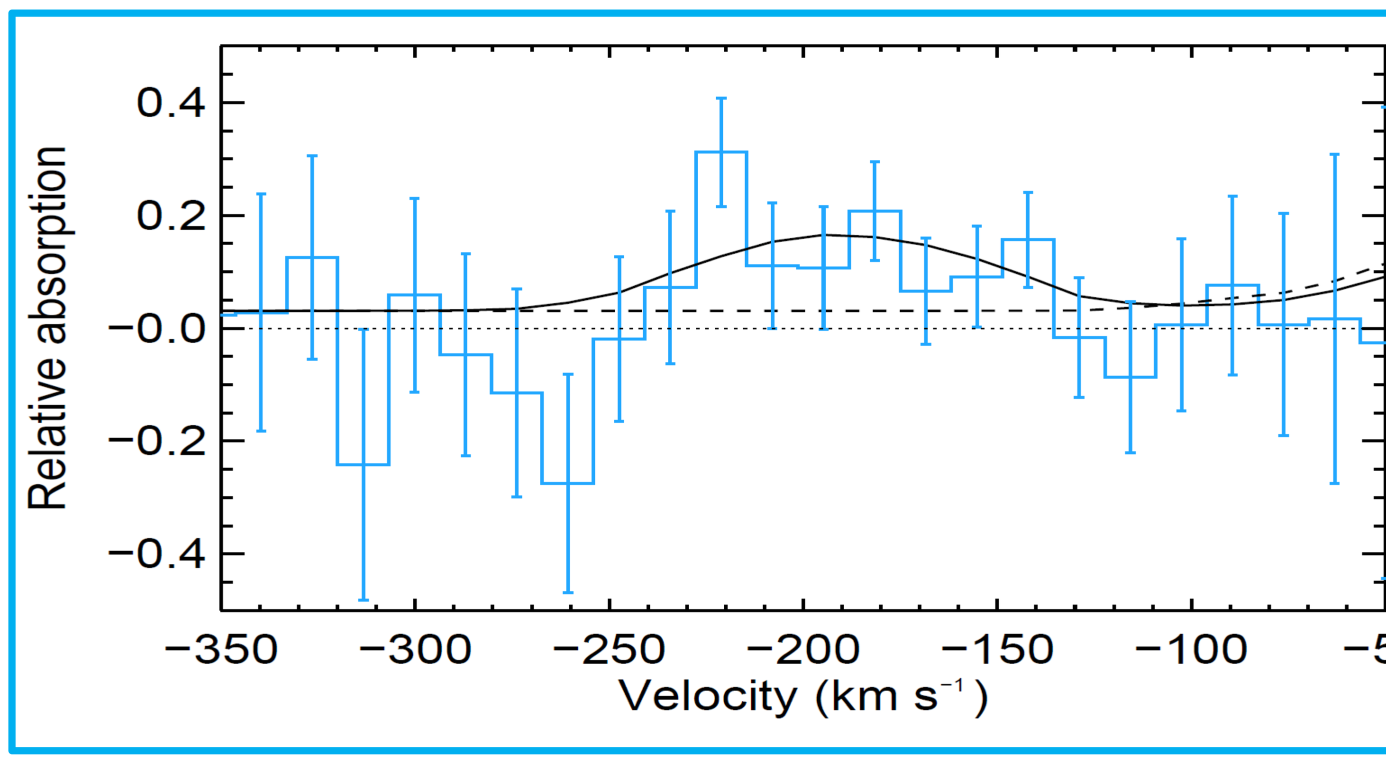

Fig. 3. Plot of the relative absorption observed in the blue wing of the Lyman-α stellar line (blue histogram) for the 2011 transit. The dashed line shows the model with radiation pressure only (no absorption at radial velocities below -120 km s^{-1}, with a large χ^2 of 22.8 for 17 degrees of freedom). The solid line shows the addition of a stellar wind and charge exchange (hydrogen atoms can be accelerated to the higher observed velocities., with a χ^2 of 13.0)

X-ray simultaneous observations

The evaporation of hot Jupiters is driven by the Xray/EUV irradiation of the planet by its parent star. In 2011, we obtained contemporaneous observations with the X-ray telescope (XRT) of the Swift spacecraft. The light curve of HD189733 (Fig. 5) shows that the star exhibits significant X-ray variability, and most notably, a **bright flare** which occurred about 8 hours before the planetary transit. This flare could explain the observed variations in the extended cloud of escaping hydrogen, as it could affect the properties of the stellar wind. Besides, the enhanced X-ray/EUV irradiation associated with this flare must lead to a significantly enhanced escape rate.

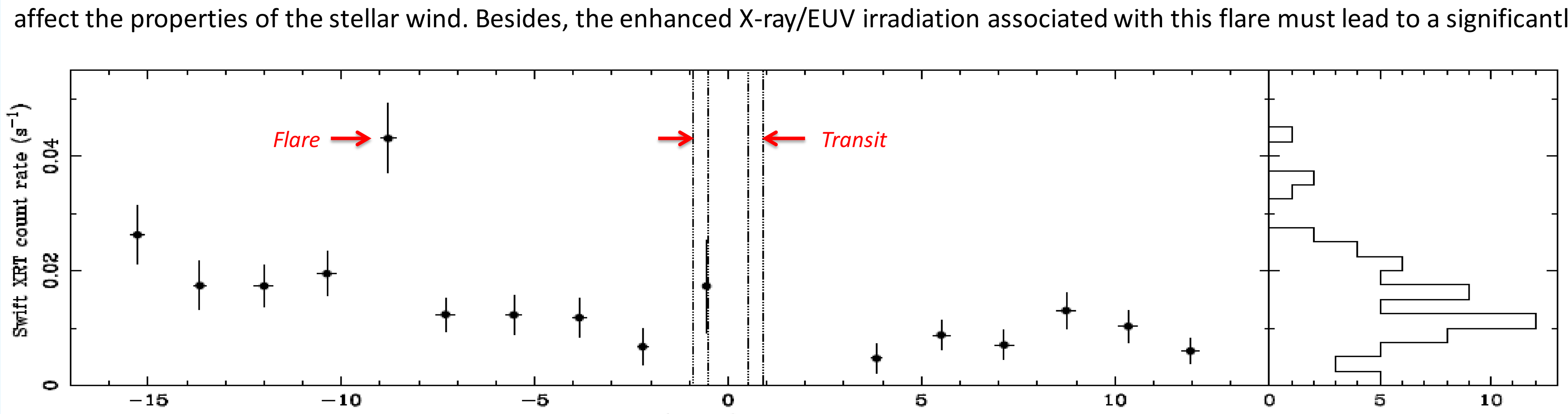

Fig. 5. Swift XRT X-ray light curve of HD189733 about the time of the 2011 transit. The data were binned into one point per snapshot visit, with typical exposure times of about 27 minutes. Vertical dashed lines show the beginning and end of ingress and egress of the transit. A bright flare occurred about 8 hours before the transit. For comparison, the right panel shows the distribution for 63 epochs of Swift measurements.

Results

- **We confirm the evaporation of the hot Jupiter HD189733b.**
- **We detect temporal variations in this evaporating atmosphere.**
- **These variations may be related to a stellar X-ray flare observed 8 hours before the transit.**
- **The 2011 absorption signature can be explained by a N-body simulation which take into account stellar wind and charge exchange with protons from stellar wind. Best fit parameters are an atmospheric escape rate of about 10^9 g s–1, a stellar wind velocity of 190 km s^{-1} and temperature of 10^5 K.**

References
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