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# An extensive search for metallic ions in the exosphere of GJ 436 b

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## Abstract

We leveraged the extensive coverage of *HST*/COS observations of the far-ultraviolet (FUV) spectrum of GJ 436 to search for metallic ions in the upper atmosphere of GJ 436 b, as well as study the activity-induced variability of the star at short wavelengths. We found that GJ 436 displays flaring events with a rate of $\sim$10 d$^{-1}$, and a long-lived activity region modulates the FUV metallic line fluxes of the star with amplitudes up to 20%. We detected the Lyman-$\alpha$ transit of GJ 436 b with COS, despite the strong geocoronal contamination. We could not find strong evidence for the presence of metallic ions in the exosphere of GJ 436 b and rule out a wide range of excess absorption levels in the fluxes of metallic lines of the star during the transit. The previously claimed in-transit absorption in the Si III line is likely an artifact resulting from the stellar magnetic cycle.

## 1. Introduction

To this date, the most spectacular observation of atmospheric escape remains that of GJ 436 b: it displays a transit depth of 56% and a long egress in the blue wing of the Lyman-$\alpha$ line caused by the extended tail of neutral hydrogen escaping vigorously from the planet [1, 2]. GJ 436 b is a warm Neptune exoplanet orbiting a nearby and relatively quiet M2.5 dwarf, and the planet lies in the lower-mass edge of the hot Neptune desert [3, 4, 5]. One of the open questions about GJ 436 b is if it is currently losing other species besides neutral hydrogen through atmospheric escape. A tentative absorption signal in the Si III stellar line (1206.5 Å) of GJ 436 was reported by [2] using *HST*/STIS, and could be of planetary nature. If proven real, this signal would suggest that Si atoms are hydrodynamically dragged from the lower atmosphere of the planet by the H atoms [6], indicating the presence of atmospheric mixing and clouds in the lower atmosphere [7]. This putative signal was, however, not reproduced in a single transit observed with *HST*/COS [8].

Aiming to resolve the open questions about GJ 436 b and the hydrodynamical nature of the atmospheric escape process, we report here on the analysis of several *HST*/COS observations obtained for the Hubble PanCET program (GO-14767, PIs: D. Sing and M. López-Morales) and other public datasets, covering different phases of the planetary transit in several epochs.

## 2. FUV stellar activity of GJ 436

Although GJ 436 is a quiet star compared to other M dwarfs [9], we observe strong levels of stellar variability in some of the lines in its FUV spectrum. Following an inspection of the time-tag split light curve of the Si III and C II fluxes, we found a statistically significant increase in fluxes by 100% during several exposures, which we interpret as stellar flaring activity (see Fig. 1). We estimate that the flaring rate of GJ 436 in FUV is $\sim$10 events d$^{-1}$.

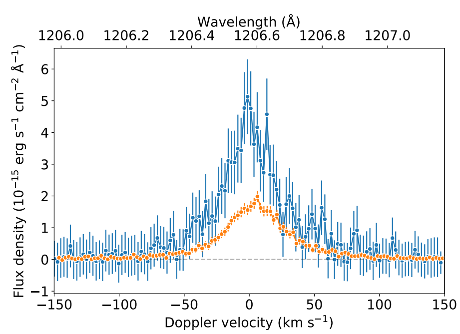


Figure 1: Comparison between the quiescent (orange) and flare (blue) spectra of GJ 436 near the Si III line at 1206.6 Å.

Additionally, we found that the fluxes of the C II doublet, the N V doublet and the Si III line in the COS data seem to display rotational modulation. To the best of our knowledge, such a modulation of FUV lines in the spectra of quiet M dwarfs like GJ 436 has not been reported in the literature before. This result indicates that GJ 436 possessed a stable active region in its corona that modulated the FUV fluxes for more than 60 rotations since the early 2010s.

## 3. Searching for planet-induced variability signals

We used COS airglow templates [10] to clean the Lyman-$\alpha$ emission of GJ 436 from the geocoronal contamination, and managed to reproduce the deep Lyman-$\alpha$ transit of GJ 436 b previsouly measured with *HST*/STIS, indicating that the large scale atmospheric loss of the planet is stable over the timescale of a few years (see Fig. 2). We searched for planetary signals during transit by phase-folding all *HST*/COS exposures to the planet's orbital period. We did not find strong evidence for additional in-transit absorption caused by the planetary exosphere in the metallic lines.

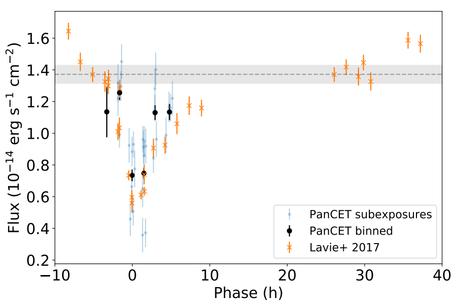


Figure 2: Lyman-$\alpha$ transit light curve of GJ 436 b using COS (blue) and STIS (orange) exposures.

Since we were unable to reproduce the result over several visits with *HST*/COS, it is likely that the Si III absorption signal reported by [2] is related to stellar variability instead of absorption by the exosphere of GJ 436 b. Approximately half of the STIS observations were obtained between 2010 and 2015, when it seems that GJ 436 was in the minimum of its activity cycle. The non-detection of metallic species in its exosphere, in particular Si, suggests that, if GJ 436 b

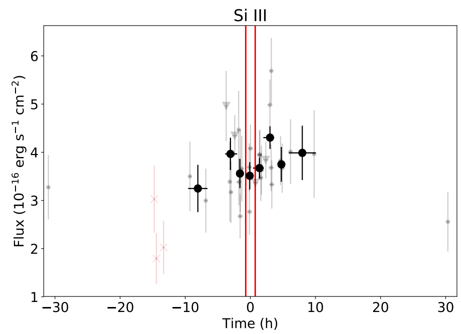


Figure 3: Light curve of Si III fluxes of GJ 436 phase-folded to the planetary transit. We could not identify significant planet-induced signals after correcting for stellar activity. The red symbols are not included in the analysis.

possesses a cloudy atmosphere, then mixing is not efficient in dragging the Si-rich clouds high enough for sublimation and allow for a significant escape rate of metallic ions. Other factors, such as atmospheric metallicity and ionization conditions also play a role in the interpretation of the non-detection.

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